THE EFFECTS OF DRY SOW HOUSING CONDITIONS ON WELFARE AT FARROWING

Thesis submitted to the University of Cambridge
for the degree of Doctor of Philosophy

by

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I hereby certify that this thesis, submitted in candidature for the degree of Doctor of Philosophy at the University of Cambridge, has not been previously submitted for a degree in this or any other University. This thesis is the result of my own investigations, and any assistance is acknowledged. The length does not exceed 60,000 words.

Jeremy N. Marchant

Summary

Measures of production, physiology, behaviour and pathology were used to assess the effects of confined and loose dry sow and farrowing housing systems on the welfare of the sow and her litter. Litter size decreased and piglet mortality increased greatly after the sixth parity, regardless of housing system, resulting in a sharp decline in the number of piglets weaned per litter. Stall-housed sows gave birth to the most piglets per sow per year, but also had the highest piglet mortality. Overall, piglet mortality was higher in farrowing pens than in crates. Sows from the large group had a significantly larger number of returns to service after farrowing in crates. Behaviourally, all sows adapted well to the farrowing house. All sows showed an increase in the number of posture changes, reaching a maximum during the 24 hours immediately prior to parturition. However, this increase was greatest in those sows in farrowing crates, which had previously been housed in an open environment. Heart rate was influenced by stage of gestation, posture and behaviour. Stall-housed sows had a higher basal heart rate and heart rate response to feeding than group-housed sows, perhaps indicating decreased cardiovascular fitness and an increased sympathetic nervous response to stimuli such as food. When farrowing in crates, group-housed sows had a higher heart rate response to the suckling event than stall-housed sows. This may be due to general unresponsiveness in stalled sows or to high reactivity to the suckling event in group sows caused by frustration of mother-infant interaction. When involved in agonistic interactions, the change in heart rate was greatest for sows which lost a physical interaction. Stall-housed sows had weaker bones than group-housed sows, and different muscular conformation, probably due to lack of exercise. Bone and muscle weakness may increase the susceptibility of stall-housed sows to lameness. When lying down, stall-housed sows had greater difficulty and took longer than group-housed sows. The times taken for stall sows to lie down and to stand up quickly were positively correlated with body length. For group-housed sows lying down in the open, the time taken was positively correlated with proportional locomotory muscle weight. Spatial restriction when lying resulted in the loss of muscular control. There was a positive correlation between body length and the number of piglets crushed for stall-housed sows and group-housed sows farrowing in crates. There was also a positive correlation between body length and crushing mortality for group-housed sows farrowing in pens. This indicates that sows can have problems controlling movements, even in the presence of piglets. The results presented reveal several welfare problems resulting from stall housing during pregnancy. It would appear unreasonable to confine sows during farrowing, if they have previously been housed in an open environment. However, not enough is known about the causes of piglet mortality and any decision concerning the continued use of farrowing crates must take account of the trade-off between sow welfare and piglet welfare.

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Publications arising from this thesis

Marchant, J.N. & Broom, D.M. (1993) The effects of dry sow housing conditions on responses to farrowing. *Anim.Prod.* **56** (3) p475-476 (Abstr.)

Marchant, J.N. & Rudd, A.R. (1993) Differences in heart rate response at feeding between stall-housed and group-housed sows. *Anim.Prod.* **56** (3) p423 (Abstr.)

Marchant, J.N. & Broom, D.M. (1993) The effects of sow housing on responses to farrowing conditions. *Appl. Anim. Behav. Sci.* **38** (1) p81-82 (Abstr.)

Marchant, J.N. & Broom, D.M. (1993) The effects of dry sow housing conditions on lying behaviour of sows. In *Proceedings of the International Congress on Applied Ethology*, 455-458. Eds. M.Nichelmann, H.K.Wierenga & S.Braun. Humboldt University, Berlin.

Marchant, J.N. & Broom, D.M. (1994) The effects of dry sow housing conditions on bone strength and muscle conformation. *Anim.Prod.* (Abstr.) In Press.

Marchant, J.N. & Broom, D.M. (1994) Lying behaviour of dry sows in relation to housing conditions. *Anim.Prod.* (Abstr.) In Press.

Marchant, J.N. & Broom, D.M. (1994) Dry sow housing-induced anatomical differences and the effects on lying behaviour. *Anim.Prod.* (Abstr.) In Press.

Marchant, J.N. & Broom, D.M. (1994) Effects of housing systems on leg strength and movement in sows. *Appl. Anim. Behav. Sci.* (Abstr.) In Press.

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CONTENTS

CHAPTER 1

An introduction to sow management and to the concepts, terminology and measurement of animal welfare

1.1 Introduction to the research

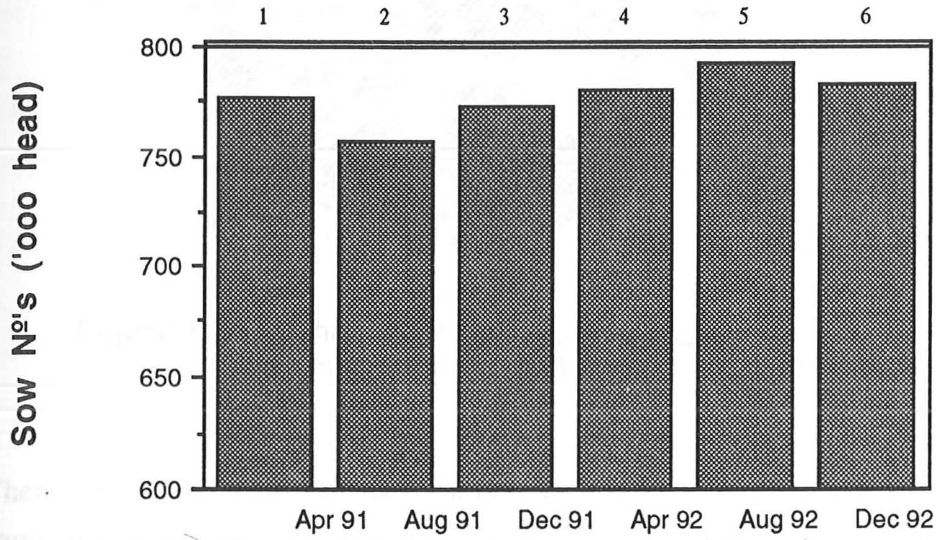
As public awareness of the concept of animal welfare has increased, it has become clear that it is far from just the vegetarian population calling for improved welfare for farm animals. Consumer demand, and in some instances legislation, are forcing commercial producers to confront the welfare issues pertaining to their livestock. As a consequence, more funding from the major grant awarding bodies, such as the Ministry of Agriculture, Fisheries and Food (M.A.F.F.) and the Agriculture and Food Research Council (A.F.R.C.), is being earmarked for welfare-related projects. These projects, it is hoped, will not only provide evidence which can be used to define and improve farm animal welfare, but also demonstrate to the producer that improving the welfare of his/her livestock need not impair productivity of the herd or flock, but may even increase it.

This chapter will describe the status and housing of the sow within the structure of the UK pig industry and introduce the concepts and terminology used in the field of animal welfare research.

1.1.1 The breeding sow and the UK. pig industry

World pig meat production is continuing to expand. Decreases in production by Eastern European countries during the restructuring of former State-run farms is being more than compensated for by increases in production in the majority of developed countries, such as Western Europe, USA and Canada. The European Community (EC) breeding herd increased in 1992 by over 3% to approximately 12 million sows (M.L.C., 1993) although total EC pig meat production fell by 1% to 14.2 million tonnes, entirely due to rationalisation of the German pig industry following re-unification.

The United Kingdom is currently the seventh largest producer in the EC, producing about 966,000 tonnes of pig meat from a national herd of 785,000 breeding sows in December 1992; a rise of 1.7% on a year earlier. The pig industry in notoriously cyclical in terms of both profit and size of national herd. There is always rapid reaction to increased market price. The prolificacy of stock enables producers to breed from pigs originally intended for slaughter and thus to fill any gap in the pigmeat market, quickly. However, any scarcity in pigmeat is invariably followed by a glut, which depresses market prices and in turn, the size of the national herd. Such fluctuations can be rapid as illustrated by Figure 1.1.



Source: MLC,1993

Figure 1.1 The mean number of sows in the UK breeding herd during 1991 and 1992.

At any one time, the breeding herd is split into two categories: 1) Dry sows & 2) Farrowing/lactating sows. The term 'dry sow' encompasses all gestating sows, sows awaiting service and barren sows within the herd. In 1991, an estimated 16% (125,000) of the sows within the UK. national herd were kept on outdoor, extensive systems (M.L.C., 1991), a number which has since increased to a current estimate of about 20%, and which is continuing to rise (Walker, pers.comm.). The rapid growth in this sector of production can be seen by comparison with the distribution of housing types seen in 1986 (see Figure 1.2).

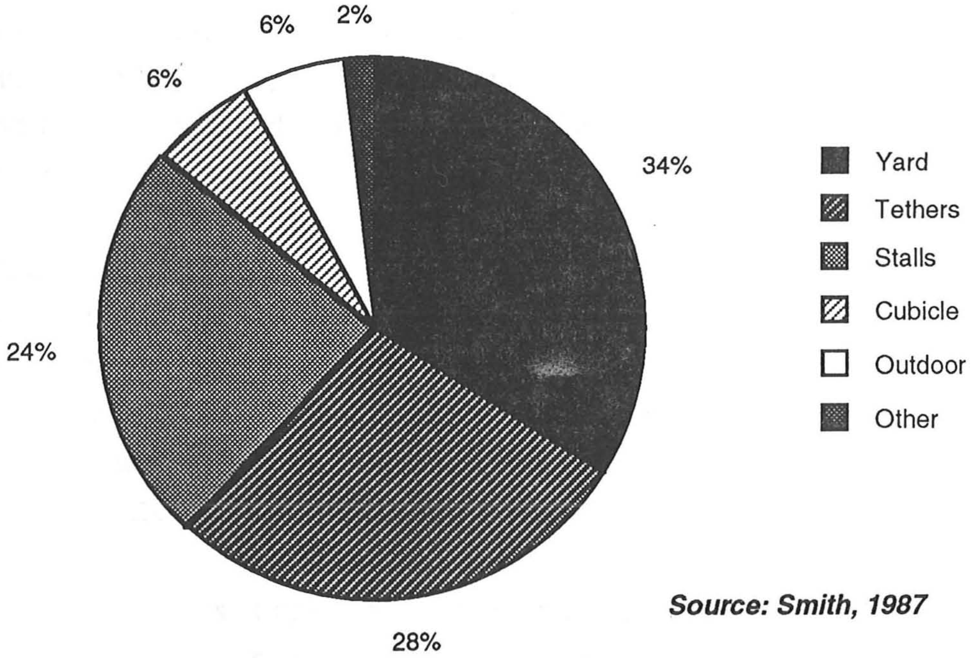


Figure 1.2 Pie-chart showing the percentage of the UK breeding herd kept in various types of dry sow accommodation in 1986.

There are a number of reasons for this growth in outdoor production. The initial driving force was consumer demand for 'welfare-friendly' alternatives to intensive farming systems. This was reinforced by legislation passed by the UK. Government in 1990, banning the use of stalls and tethers by the start of 1999, with an immediate ban on their installation in new buildings. For farmers having to replace such systems, or wishing to expand, outdoor production requires minimal financial input. There has also recently been implementation of a 'set-aside' policy for European agriculture, in an effort to decrease surpluses of arable crops. This has resulted in some farmers seeking to make use of land which would otherwise be lying fallow. Presently, 80-85% of the national herd (approximately 630-670,000 sows) are being kept in indoor systems with varying degrees of intensity, ranging from individual stalls or tethers, through small group housing to large group housing with electronic feeder systems.

1.1.2 Management of an average UK breeding herd

The average 1992 breeding herd in the MLC Pigplan Management Service consisted of 251 sows and gilts, kept in a variety of dry sow systems, but mostly farrowing in crates (90%).

The sows are usually moved to the farrowing house five to seven days before the predicted farrowing date 114 days after service, in order to allow time to settle in before parturition. Average live litter size is 10.76 with pre-weaning mortality of 11.7%. The majority of units now wean between 19-32 days (93%) with the average about 24-25 days. The trend in the 1970's and 1980's towards earlier weaning at or before 21 days, has reversed slightly in line with welfare recommendations and production evidence.

After weaning, the sow is usually moved to a special service area with boar contact, which encourages œstrus. After serving, she will remain in the service area for three to four weeks, where the stockman will watch for any signs that the pregnancy has not held, i.e. signs of œstrous behaviour at 21 days after service. She will then be returned to the dry sow system. A return to service occurs in approximately 14% of all sows and gilts served. Overall output is about 2.26 litters per sow per year. Sows which consistently return to service or have litter sizes well below the average, will be culled and replaced. Most units will also cull on the basis of age or parity number alone. Thus, annual sow replacements run at 41% of the herd, the majority due to the reasons above, but also approximately 4% due to sow mortality through illness or disease (see Figure 1.3).

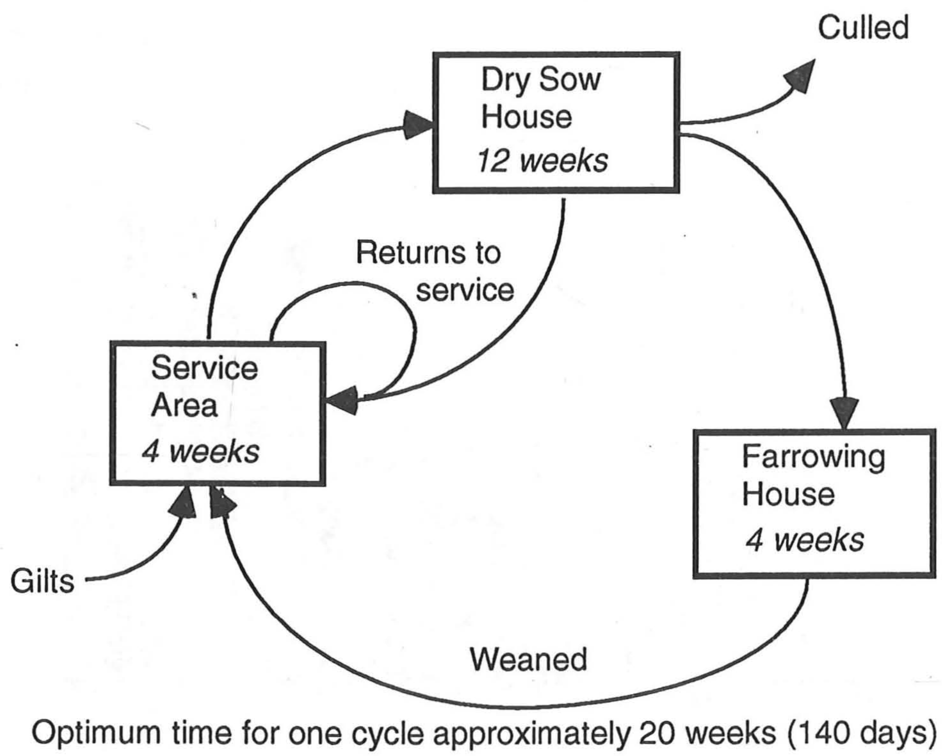


Figure 1.3 Diagrammatic representation of the sow management cycle.

1.1.3 Dry sow housing systems

There is a great diversity of dry sow housing systems currently in use in the UK. The last few decades have seen sow housing move from extensive to intensive. As noted above, however, forthcoming legislation will somewhat reverse this trend and force the UK industry to extensify. An M.L.C. survey in 1991 stated that within the UK national herd, 16% of sows were housed outdoors, 55% housed indoors in straw-based systems and 31% housed indoors in stalls or tethers. This compares with a figure of about 70% housed in stalls or tethers in Denmark and the Netherlands. Thus, the UK industry is not now as intensive as some within the EC.

Until recently, the major factor behind sow house design, was that of economics of production. Since World War II, there has been a reduction in the number of individual pig producers but a four-fold increase in the size of the national herd. The trend away from extensive systems with small herd numbers towards larger intensive units was initially fuelled by Government-backed price incentives in the late 1940's and accelerated during the 1950's as new, intensive system-based technology was applied. The cyclical effect of pig production discussed previously also accelerated the decline of the small producer. It made economic sense to increase herd size, increase stocking densities, increase turnover and decrease labour costs by mechanisation where possible (see Figure 1.4).

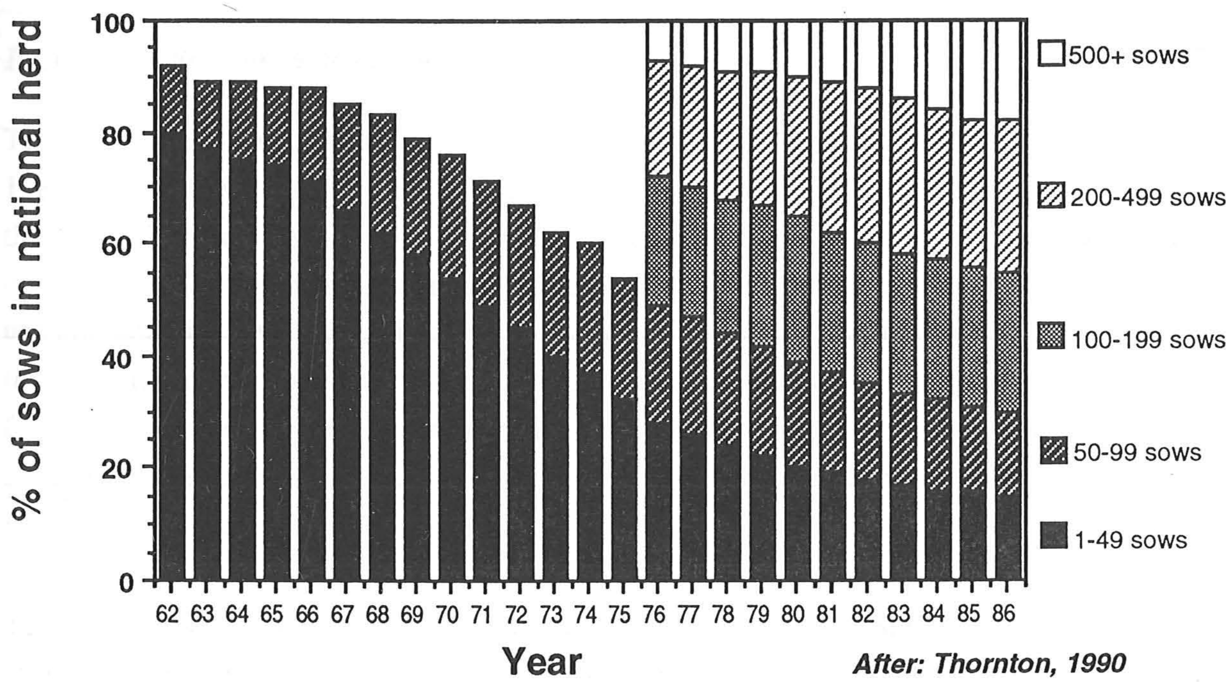


Figure 1.4 The proportion of sows in different herd sizes in the UK breeding herd from 1962-1986.

The ultimate developments in terms of dry sow housing, were those of stalls and tethers. Keeping the sows in permanent confinement gave the farmer a number of advantages over less intensive systems. For example:
1) Stocking Density. A larger number of sows could be housed in a given area compared with loose-housed systems.
2) Cost Effectiveness. Housing sows on concrete with incorporation of a mechanised slurry-handling system reduced both straw and labour costs.
3) Ease of Management. The stockman is able to monitor individual sows easily and adjust husbandry regime where necessary.
However, it has since become apparent that such intensive systems may also have a number of disadvantages in terms of the welfare of the sow, which has led to the UK ban on these systems.

Until fairly recently, the most common straw-based system for dry sows was that of small groups with individual feeder stalls into which the sows were shut during manual feeding. The last few years have seen a number of new, or in some instances 'revitalised', systems for keeping sows in larger groups. The sow house is basically similar for all these, with differing methods of feeding. These include the use of electronic feeder systems, 'dump' feeder systems and 'trickle' feeder systems.

1.1.4 Farrowing sow housing systems

There is also a diversity of housing types for farrowing. The majority of sows (over 90% in 1986, Smith, 1987) are confined in crates during the whole farrowing period in the belief that this minimises piglet mortality. Prior to intensification, sows most often farrowed in open pens with large amounts of straw. Again, economics forced development. As straw use and pen-size decreased, piglet mortality was found to rise. Introduction of crates into this situation, was found to reduce mortality back towards pre-intensification levels. Coupled with this effect on piglet mortality, which is the main reason given by farmers for continued usage, crates were also found to confer management benefits, such as reduced labour costs and ease of piglet handling.

The great amount of research on modification of farrowing crate design has yet to improve piglet mortality much below 10%, and this fact, together with concerns for the welfare of the sow and a desire for alternative systems that require minimal financial input, has led to a re-examination of the factors necessary for defining the optimum farrowing conditions.

As with the dry sow housing, there has been recent development of both new and old farrowing systems. A return to basic individual straw pens with farrowing rail has often given increased mortality from crushing, as the sow is given greater freedom of movement. Other designs include circular or oval crates (Lou & Hurnik, 1993) or incorporation of farrowing areas into communal systems (e.g. Baxter, 1991, Rudd et al, 1992). In most of these cases, full investigation of potential has yet to be carried out, but initial results would seem to suggest that piglet mortality can at least be brought down to levels comparable with conventional crates, without the restriction of the sow. A greater understanding of the factors affecting piglet mortality could eventually lead to a reduction in this figure which would have massive welfare and economic implications.

Whereas economics is still a factor in housing development, the changing attitudes of consumers towards less confinement for meat animals, is the main driving force behind the current trend in sow housing systems. With close confinement of the dry sow now deemed to be unacceptable in the UK, yet confinement of the farrowing sow still acceptable, it is probable that most sows will now move from a loose-housed system during gestation to confinement at farrowing. It is therefore very important that any effects of the combination that confinement and freedom have on the welfare of the sow be fully investigated. Attempts to determine to what extent changes from freedom to confinement and vice versa have on the welfare of the sow and her litter are the central theme of this thesis. Before explaining this, the definitions of welfare and associated terms used in this thesis require further discussion.

1.2 Concepts and terminology

1.2.1 Defining animal welfare

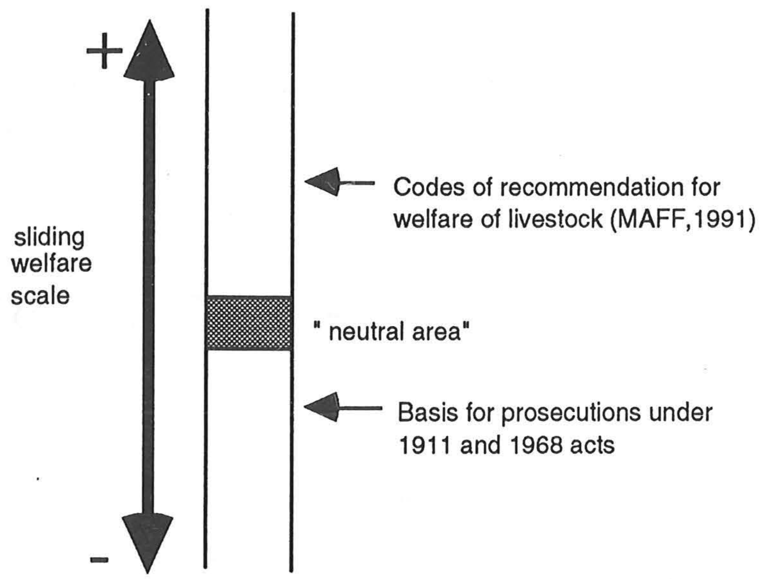
The Oxford dictionary defines welfare as " *satisfactory state, health and prosperity* " or "*well-being* ". This fails to recognise that welfare exists as a 'sliding scale', ranging from very good to very poor. Many researchers have implicated 'well-being' in their definitions which, as a feeling, defies quantifiable assessment. Others such as Duncan & Dawkins (1983), freely use welfare and well-being synonymously. It is imperative to avoid colloquialisation of such terms as well-being and welfare, and to define each with different meanings.

The Brambell Committee (Command paper 2836, 1985) stated that "*welfare is a wide term that embraces both the physical and mental well-being of an animal* ." This statement as a whole, would be far more acceptable if "state" replaced the term "well-being". Carpenter (1980) said that "*the welfare of managed animals relates to the degree to which they can adapt, without suffering, to the environment designated by man. So long as a species remains within the limits of the environmental range to which it can adapt, its well-being is assured.*" By the addition of the phrase "without suffering", he defines welfare as a state which is only good. The second sentence again shows the synonymous use of welfare and well-being. Hughes (1976) defined welfare as "*a state of complete mental and physical health, where the animal is in harmony with its environment* ", echoing Lorz (1973) who defined the welfare of an individual as" *the existence in harmony with itself and with the environment, both from an ethological and physiological point of view* " .

It could be argued that, because of the dynamic nature of an environment, no animal is ever in continuous harmony with its environment but is either coping or failing to cope (see Section 1.2.2). Hughes' and Lorz's definitions are somewhat idealistic in this respect and again, the definitions only pertain to welfare as being good. Broom (1986a) uses the definition " *the welfare of an individual is its state as regards its attempts to cope with its environment*". This definition recognises the range of welfare from good to bad, and introduces the concept of 'coping', and will be the one referred to in this thesis.

There is no doubt that the arguments over the definition of welfare will continue, as researchers will all have a personal point of view as to what should be included. Certainly, an animal's welfare ranges, at any one time, on a scale from very good to very poor. It contains both physical and mental elements. The physical elements are measurable by a number of means described later, but the mental elements remain harder to quantify. Welfare scientists are able to determine an individual's welfare as long as physical elements are present. It may be argued that mental welfare in humans can be poor without any obvious physical signs, e.g. in certain types of depression. If this can be paralleled in animals, it would be impossible to define the welfare of those affected.

All the above definitions of welfare are devoid of any moral considerations. The welfare of an individual can be measured and described as a point on the sliding scale (see Figure 1.5). The point on the scale may be fairly indisputable, but a person's interpretation of whether this point is acceptable or unacceptable will vary according to their personal moral considerations.



After: Ewbank,1988

Figure 1.5 Diagrammatic representation of the welfare scale.

1.2.2 Defining coping and adaptation

If an animal is placed into an adverse environment, i.e. one that is physically or physiologically hostile or 'stressful', it will attempt to counteract adversity by employing various responses, both behavioural and physiological. This process of adjustment is termed adaptation. If adaptation to adversity is successful, the animal can be deemed to be coping. If an animal fails to cope, this failure will become apparent by a reduction in biological fitness. i.e. there will be a reduction or cessation of reproduction either as a consequence of late return to œstrus or even non-œstrus, reduced number of offspring and in extreme cases, premature death.

An animal's response will be controlled by the Central Nervous System (CNS) and will be dependent on the individual's "brain state" when an environmental change is perceived. The individual will then respond behaviourally and/or physiologically. These adaptive processes aim to decrease the activating effects of environmental stimuli (Dantzer et al, 1983), and will feed back to the brain, resulting in alteration of the "brain state" (see Figure 1.6). Behavioural changes may also result in modification of the initial environmental stimulus; e.g. a skunk may emit its anal gland secretion and thus deter an attack. Other factors that may modify "brain state" and thus adaptive responses include genetic factors and previous experience. Much work has been done in pigs looking at differences in responses to stress in genetic strains with different halothane sensitivity (e.g., Honkavaara, 1988, Rundgren et al, 1990).

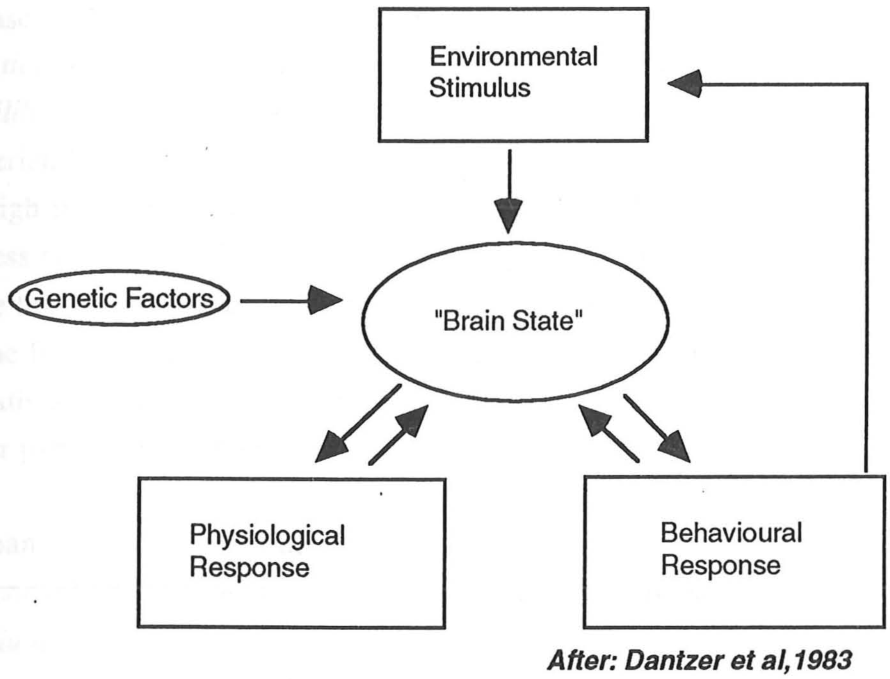


Figure 1.6 A model of the relationship between environmental stimuli and adaptive processes

As stated, coping may occur through modification of behavioural pathways or physiological pathways, or a combination of both. The relative degree of use by animals placed into the same hostile environment will be species dependent. Superimposed upon any species difference, there will be variation of response between individuals of the same species. An illustration of individual variation is incidence of stereotypic behaviour of sows housed in close confinement. Dantzer and Mormède (1981) found that tethered sows with high stereotypic incidence had lower plasma cortisol levels than non-stereotyping sows. Schouten & Wiepkema (1991) also showed that high stereotyping sows had lower heart rates than low stereotyping sows.

1.2.3 Defining stress

The term stress, to the physical scientist, applies to any external force that causes displacement from the equilibrium it is acting on. It has now become a colloquial term and is popularly recognised as being 'bad' or an entity which causes adversity. Thus, recent definitions refer to some form of adversity as opposed to Block (1985) who described stress as "*any displacement from the optimum state* ". Broom & Johnson (1993), describe stress as " *an environmental effect on an individual which over-taxes its control systems and reduces its fitness, or appears likely to do so* ". Thus by introducing "reduced fitness", it is implied that an adverse change is only a stress if fitness is, or will be, affected.

Manser (1992) defines stress as occurring when *"an animal encounters adverse physical or emotional conditions which cause a disturbance of its normal physiological and mental equilibrium"*. This allows for the interpretation that an animal can be under stress without experiencing any loss of fitness. A reduction in fitness of an individual is an obvious way of high-lighting the poor welfare of that individual. However, it is not a prerequisite that fitness must be impaired for welfare to be poor. An individual that adapts and copes may have to employ considerable physical and physiological effort without this being apparent in the form of reduced fitness. The welfare of this individual cannot be classified as good or satisfactory on the basis of fitness alone. Indeed, its welfare may be very poor and, thus, other parameters need to be examined closely.

Ewbank (1985) subdivides stress into *overstress* and *distress*, the use of which is dependant on the biological cost to the animal. He applies *overstress* for an *"adaptive, medium-level response, which has been made at biological cost with some damage to the animal"* and *distress* for *"the high-level response which has a high biological cost and is damaging to the animal"*. Introduction of further terms does little to clarify the picture, and in fact achieves the opposite. To assess an animal as *stressed* is work enough. To then attempt to assess *overstress* or *distress*, is unnecessary.

1.2.4 Assessment of animal welfare

As stated earlier, legislation exists in many countries in order to define a minimum welfare standard that is applicable not only to livestock, but to the majority of animals within its jurisdiction. However, just as there are variations between individuals as to what are acceptable welfare standards, there is also variation between countries. Much of this variation may be deep-rooted into the national culture, e.g. the acceptability of bull-fighting among people of Iberian descent. In such a case, attempts to change moral attitudes through education need to be backed up by scientific assessment. Also, where legislation is enforced, successful prosecution will need welfare to be assessed scientifically and is best achieved by using an amalgam of different measures (Smidt, 1983, Broom, 1988). These are outlined below, and where relevant, will be discussed in more detail in Chapters 2 & 3.

1.2.4.1 Measures of production

For farm animal species, an easy first indicator of the welfare of stock is productivity. It is most likely that a failure to cope, or extreme difficulty in coping, with the environment will manifest itself as a loss of production, although a few individuals with poor productivity may be masked by the whole herd or flock, and therefore individual records should be scrutinised.

In a breeding herd or flock, failure to cope will ultimately lead to death either from natural causes, as a consequence of the over-taxing of its physiological and behavioural adaptive responses, or as a result of culling due to reproductive failure. In a rearing herd or flock, the animal will usually be slaughtered for meat production before death due to failure to cope, but welfare problems may be apparent due to raised mortality levels and poor growth or weight gain. For the individuals affected, welfare is undoubtedly very poor. However, on a commercial farm, welfare problems may only warrant investigation for production reasons.

Loss of productivity can usually be apportioned to disease, the effects of housing system or the effects of husbandry techniques. There will always be a characteristic incidence of disease on a particular farm, with characteristic levels of mortality and morbidity, without any environmental effect. However, inadequate housing or husbandry may cause mortality and morbidity to rise either as a result of poor hygiene or as a result of increased susceptibility to disease caused by stress-induced immunosuppression. This relationship and its consequences for breeding stock, are illustrated in Figure 1.7.

a) Mortality

Housing design can have a great effect on subsequent mortality levels. An area of much research has been that of farrowing crate design. Piglet mortality is seen to vary greatly depending on housing conditions (e.g. Vermeer et al, 1993, Curtis et al, 1989). Transportation can also affect mortality, as seen in studies on hens (Swarbrick, 1986), calves (Barnes et al, 1975) and pigs (Sybesma et al, 1978). Poor husbandry techniques will also have a major effect on mortality levels: e.g. mixing stable groups of hens has resulted in increased mortality (Gross & Siegel, 1981).

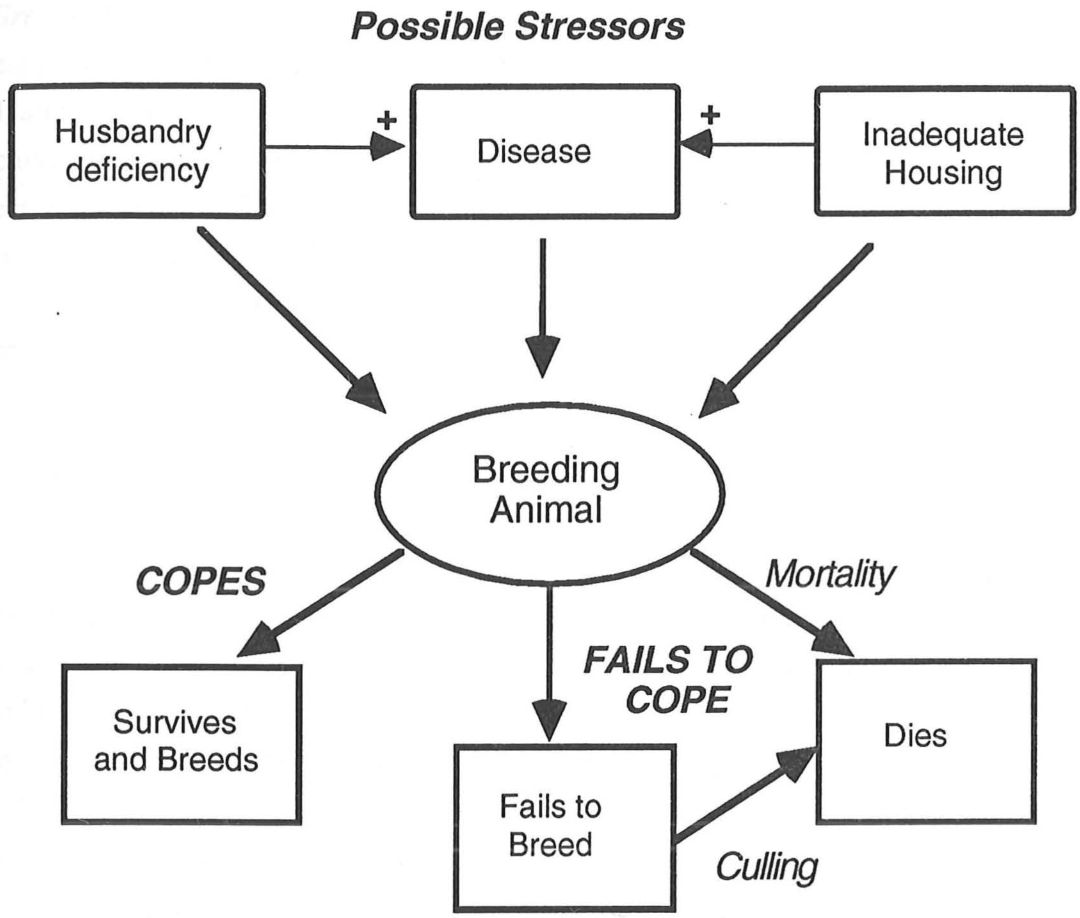


Figure 1.7 Diagram of the possible stressors that may affect breeding stock, and their possible consequences.

b) Reproductive failure

Housing conditions may also result in reduced reproductive success. Free-range hens may suffer severely reduced egg production during extreme weather conditions (Sainsbury, 1980). Sows housed in groups where aggression is a problem, may return to service more frequently and have a tendency to give birth to smaller litters (Bokma, 1990, Svendsen & Olsson, 1991), but sows housed in stalls may give birth to more stillborn piglets (Bäckström, 1973). Acute stress can also cause spontaneous abortion, e.g. as seen in sheep following attack by dogs.

c) Growth rates

Stressors have been shown to affect growth rates of a number of species. Mixing of heifers with strangers has been shown to depress growth rates (Haggett et al, 1982) as has mixing of calves (Broom & Leaver, 1978, Broom, 1982). Mixing of gilts has also shown this effect, with weight gain dependent on dominance (Mendl et al, 1992). Social isolation of hens can similarly result in decreased growth rate (Gross & Siegel, 1981). Aversive handling can affect growth rates of pigs housed singly (Hemsworth & Barnett, 1991) and in groups (Gonyou et al, 1986).

1.2.4.2 Behaviour studies

The study of behaviour can be a very useful tool in the assessment of welfare (Ödberg, 1987, Wiepkema, 1987). Alteration or disturbance of normal behaviour patterns can be the first sign of illness or disease and thus, an important indicator of the welfare of an individual. In fact, a veterinarian will usually make an initial diagnosis on the basis of observed or described behaviour patterns, such as changes in posture and locomotion, together with alteration of feeding, drinking and eliminative behaviours. Differences from normal behaviour will, at the very least, indicate possible causes and in many cases will lead to immediate diagnosis. There are numerous illnesses and diseases which have very specific behaviour changes associated with them, and which give rise to descriptive colloquial names, e.g. 'mad cow disease', 'splayleg' and 'grass-staggers'.

However, there may be an increased incidence of abnormal behaviour which is not associated with any physical illness but instead is related to the amount of stress that the individual is experiencing. Such behaviour may commonly take the form of a distinct invariant repetitive pattern of movements that has no obvious function. These patterns are termed stereotypies and have been shown to occur in a wide range of captive and farm animals usually as a direct result of confinement or isolation in a barren environment. They take a wide range of forms including pacing (in hens, Brantas, 1980), rocking or weaving (in horses, Broom & Kennedy, 1993), head-swinging (in zoo-kept bears, Dittrich, 1984), wind-sucking (in horses, Kennedy et al, 1993), crib-biting (in horses, Brion, 1964), bar-biting (in sows, Fraser, 1975, Wiepkema et al, 1983), sham-chewing and drinker-pressing (in sows, Broom & Potter, 1984). The housing system may also affect an animal's locomotory behaviour or movement. Caged hens are unable to carry out wing-flapping and dust-bathing behaviours. Tied dairy cows cannot exercise and have difficulty in lying and standing (Herlin, 1990) as do stalled sows (Marchant & Broom, 1993).

There may also be self-directed or environment-directed behaviours such as excessive grooming, overeating, polydipsia, and eating, sucking or licking of non-food materials, such as wood or floor substratum. Housing in groups can result in abnormal behaviour directed at other animals. Examples of this type of behaviour are numerous, and include feather-pecking (Wennrich, 1975), tail/vulva biting (in pigs, Dougherty, 1976), scrotum or prepuce-sucking (in calves, Kiley-Worthington, 1977), belly-nosing (in pigs, Schmidt, 1982) and wool-pulling. There may also be wrongly directed sexual activity such as mounting between animals of the same sex. At parturition, there may be neonatal rejection, as seen in sheep (Arnold & Morgan, 1975), in cattle (Donaldson, 1970), in horses (Houpt & Olm, 1984) and pigs. Rejection may be confounded by direct maternal aggression leading to death and even cannibalism, or the neonates may be 'stolen' by other animals. The majority of problems at parturition seem to occur in primiparous females, i.e. females with no previous experience of rearing.

Inadequacy of the housing environment may alter an animal's levels of activity or reactivity. Prolonged inactivity has been reported in many species (Wiepkema et al, 1983). It is particularly prevalent in stalled and tethered sows (Jensen, 1980, 1981) compared with sows housed in semi-natural conditions (Wood-Gush, 1988). These sows may also be more unresponsive to various stimuli than group-housed sows (Broom, 1986b, 1986c). Severe submissive inertia is termed tonic immobility (Fraser, 1960), which may be described as an extension of the normal 'freezing' response shown by some species when threatened by a predator. It has been documented in sheep, cattle, deer and poultry, usually in association with certain husbandry techniques such as transport or handling. Other behavioural disturbances include hyperactivity and hysteria.

1.2.4.3 Physiological measures.

There are a wide variety of physiological measures available to aid the assessment of an animal's welfare. These include either direct measurement of the components of the sympathetic-adrenomedullary axis and the hypothalamic-pituitary-adrenocortical axis (see Figure 1.8) or measurements of activity of their target organs, such as heart-rate, respiration-rate and blood pressure. The sympathetic-adrenomedullary (SA) axis conveys a short-term response to stressors and is under the control of the limbic system. Direct sympathetic stimulation of the adrenal medulla, results in temporary release of adrenaline into the blood stream, which prepares the animal for 'fight or flight'. The hypothalamic-pituitary-adrenocortical (HPA) axis acts over the longer term to release glucocorticoids.

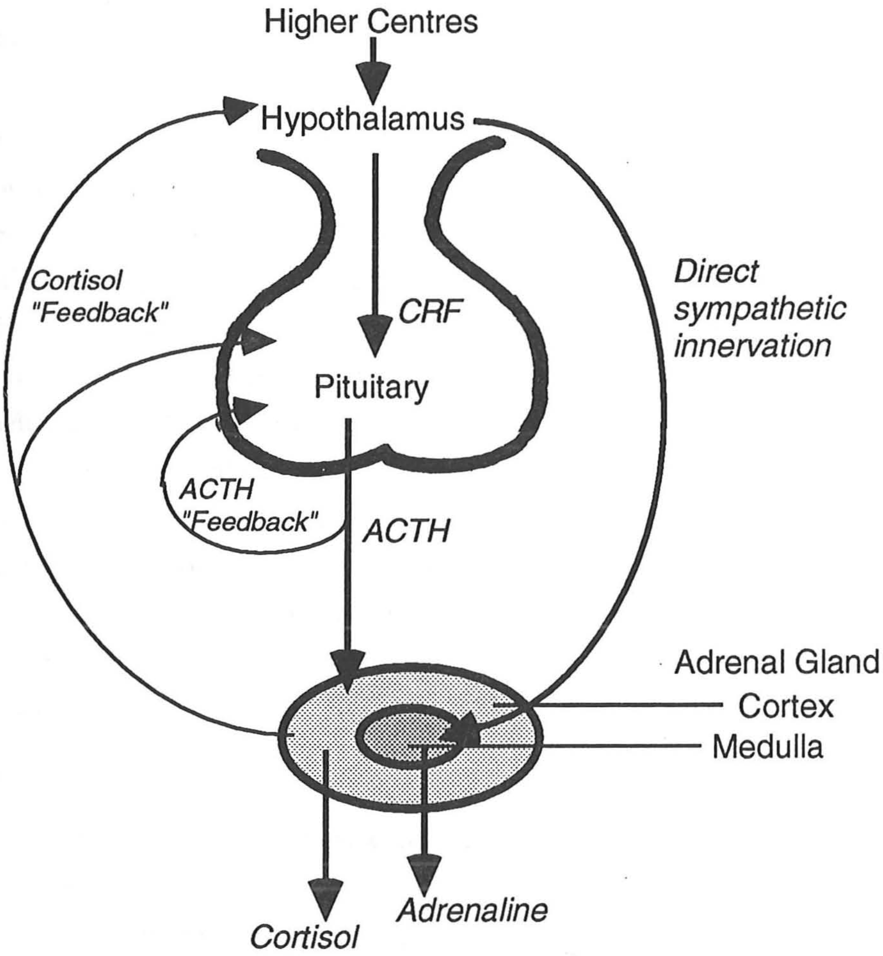


Figure 1.8 Diagrammatic representation of the mechanisms involved in adrenal gland control.

Adrenaline works by stimulating carbohydrate metabolism to provide an immediate energy source for "fight-or-flight" responses. Among its effects are increased gluconeogenesis in the liver and skeletal muscle, stimulation of stronger and faster myocardial contractions, elevation of arterial pressure and cardiac output, and dilation of bronchial musculature. Measurement of plasma levels of circulating adrenaline are impractical because 75-90% is in the form of biologically inactive sulphur conjugates, and the active form having a half-life of only 1-3 minutes. Thus, as stated earlier, the most practical method of measuring state of sympathetic arousal is by monitoring activity of target organs, the easiest indicator being heart rate.

Use of heart rate measurement as a welfare indicator has increased as monitor technology has improved. It has been used to investigate the effects of a variety of stressors including presence of humans (in calves, Stephens & Toner, 1975), loading and transport (in pigs, van Putten & Elshof, 1978), and mixing and visual isolation (in sheep, Baldock et al, 1988). Recent research will be discussed further in Chapter 2.

Glucocorticoids are released from the adrenal cortex under the influence of pituitary Adrenocorticotrophic Hormone (ACTH) which is in turn under hypothalamic control via corticotrophin releasing hormone (CRF) (see Figure 1.8). Their major target organs are the liver and thymus, where they act to produce gluconeogenic enzymes which enhance the conversion of proteins to glucose. The predominant glucocorticoid secreted by many mammals is cortisol with a half-life of 60-90 minutes, the majority of which circulates in a reversible globulin-bound form (90%). Adrenocortical responses to acute stressors last a few hours and thus, cortisol concentrations are directly measurable both in plasma and saliva. Measures of free cortisol have been used extensively as an indicator of stress during a number of acute procedures such as transport (in hens, Freeman et al, 1984 and in calves, Mormède et al, 1982), handling, restraint and minor operations. However, it must be taken into account that the output of cortisol is pulsatile and follows a circadian pattern. There is also a relationship to physical activity. Thus, single point samples offer no real indication of an animal's welfare, and for long-term assessment, cortisol measurement needs refinement.

The ACTH challenge test has been developed to show to what levels cortisol concentrations can rise, under maximal stimulation by ACTH injection, and thus give some measure of the degree of past activity of the adrenal glands. Extensive work has been carried out on many farm animal species. In sows, the long-term effects of confined and loose housing systems have been investigated (Mendl et al, 1992), and also a comparison of the responses of sows kept in different housing systems, to loading and handling (Barnett et al, 1984).

Changes in neurotransmitter activity is another physiological measure that can be used as a welfare indicator. It has been established that the secretion of endogenous opioids, such as ß-endorphin and enkephalins, can exert analgesic effects thus modifying sensitivity to pain (Akil et al, 1984), and that a range of stressors lead to an increase in activity of these opioids (Amit & Galina, 1986). The extent of this self-induced analgesia has been tested in pigs by use of the tail immersion test (Dantzer et al, 1986), and endogenous opioids have been implicated in the manifestation of stereotyped behaviour (Cronin et al, 1985, 1986).

1.2.4.4 Immunological measures

There has been a great deal of research into the effects of stress on the immune system and consequently, it is now well-established that stress can have an immunosuppressive effect. Raised levels of circulating glucocorticoids are known to have an immunosuppressive effect, but some immune suppression has been shown to be independent of adrenal activity (Esterling & Rabin, 1987). Other hormones that have been implicated include catecholamines and opioids.

Many wide-ranging reviews have been produced dealing with examples from many species and implicating a variety of stressors which have been shown to cause immune suppression (Kelley, 1985, Breazile, 1988, Manser, 1992). Size and composition of social group has been shown to affect the immunity of mice and rats (Peng et al, 1989, Steplewski et al, 1987). Separation, both peer and maternal-offspring has been shown to cause immunosuppression in primates (Coe et al, 1989, Reite et al, 1981). Other factors demonstrated to affect immunity include restraint (Steplewski & Vogel, 1986), transport (Murata, 1989), noise (Monjon & Collecter, 1977) and the general effects of housing and handling (Giraldi et al, 1989). All these are likely to be encountered during the life of a farm animal and thus must be taken into consideration by the farmer together with the obviously detrimental stressors of food deprivation and water restriction.

1.2.4.5 Pathological measures

The usefulness of pathological measures tends to be limited as they can only be fully investigated post-mortem. Thus, they are only useful in elucidating what the welfare of an individual in a system was like during its lifetime and for providing pointers to the welfare of similar individuals living in the same system. Stress-related pathologies are known to develop over the long-term and the short-term, and can include cardiovascular and renal lesions, gastric ulceration, hypertension, skeletal muscle changes and changes in weight of certain organs.

Another useful pathological measure that is affected by long-term housing conditions is bone strength. Much research has been carried out on poultry. McLean et al (1986) found stronger tibiae in aviary layers than caged layers, and noted that aviary birds typically moved seven times as far during a specified time period. Knowles & Broom (1990) have also noted similar differences in bone strength between hens housed in different systems. Other possible factors that may influence bone strength include genetic strain (Rowland et al, 1972), diet and reproduction. In pigs, there have been numerous studies into the dietary effects, but none specifically into the effects of confinement on bone strength. Long-term confinement, especially whilst an animal is still growing, may lead to increased incidence of osteochondrosis which has been shown to be widespread in young breeding sows between the ages of 1-1$^1/_2$ years (Grøndalen, 1974).

The use of meat quality to elucidate the welfare of the individual previous to slaughter has been widespread in studies of handling and transport procedures. Glycogen metabolism in muscle is affected by response to stress before slaughter (von Mickwitz, 1982). Acute or chronic stress may result in pale, soft, exuditive (PSE) meat, where glycolysis is rapid and pH falls, or dark, firm, dry (DFD) meat where glycogen is depleted prior to death and pH remains high. Long-term confinement appears to result in different muscle conformation and measurements of specific locomotory muscle mass and proportion to total body weight, may account for the difficulties in movement encountered by confined animals.

It is important that there is not excessive reliance on any one indicator alone. Assessment of an individual's welfare can be made scientifically, but should include as many indicators as possible to eliminate the risk of error.

CHAPTER 2

Literature review of the relevant indicators of animal welfare

2.1 Introduction

The welfare of an individual can be assessed scientifically using the range of indicators reviewed in Chapter 1. This Chapter will review the research carried out on farm animal welfare that has relevance to the contents of this thesis. It is not a comprehensive review of all species, but concentrates on research carried out on pigs, and more specifically, on sows. However, some areas covered in the experimental chapters have not been previously applied to pigs, and in these cases, the literature review relies heavily on research on other species.

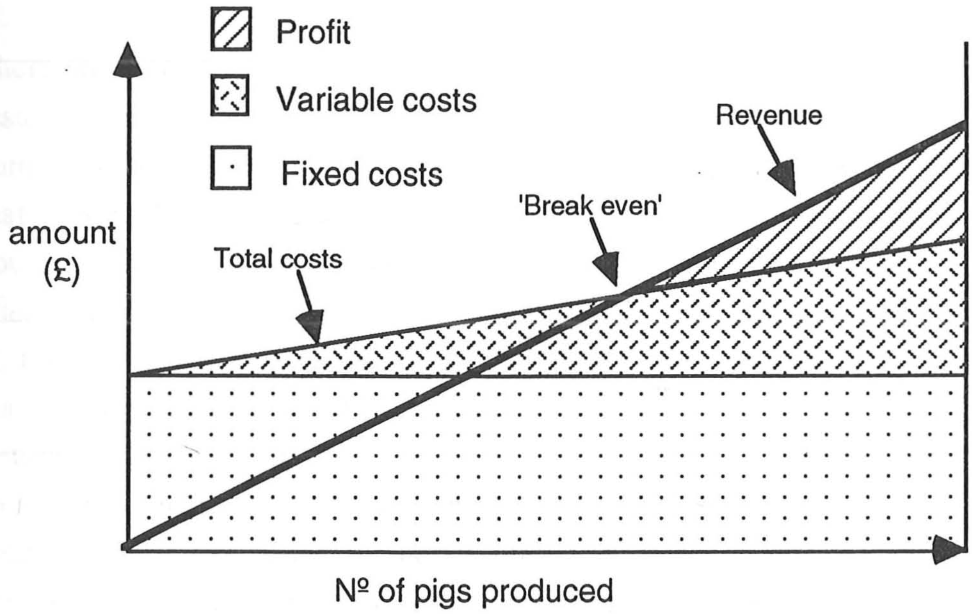
2.2 Herd production indicators

2.2.1 Introduction

To the commercial producer, any assessment of a housing system must take account of production. Ultimately, production also needs to be considered by the welfare scientist. Any research whose objective is to improve the welfare of farm animals must result in, at the very least, minimal financial loss if they are to be accepted voluntarily by those in the industry, rather than being enforced by legislation. However, the commercial producer must also take public opinion into account. The pig industry cannot afford to have a great public antipathy towards its methods, as this may result in a fall in demand for intensively farmed pigmeat products.

For any livestock breeding herd, the farmer is hoping to produce the maximum possible number of offspring per breeding female. The nearer to this maximum value the producer can achieve, the greater the profit. Profit can be seen as output value minus input costs. For the pig breeder, the output value is dependent on the number, weight and quality of weaned piglets produced. The input costs comprise of both costs which are more or less fixed (e.g. labour, machinery, sow replacement) and variable costs (e.g. feed, straw, veterinary costs) which can increase with output and also independently (see Figure 2.1).

In order for research results to become accepted within the industry voluntarily, they ideally need to be immediately financially beneficial. If they are not, as in the case of the phasing out of stalls and tethers, they may need to be legally enforced. Improvement of profit margins can either be made by an increase in output or a reduction in costs. The greatest opportunity in reducing costs is that of food, which accounts for about 70% of total costs. There is a vast amount of research aimed at pig nutrition, in order to give maximum sow and piglet performance for minimum input in terms of cost. This is outside the scope of this review. For recent reviews of the metabolic influences on sow productivity, see Pettigrew & Tokach (1991, 1993).



After: English et al, 1977

Figure 2.1 Diagram showing the relationship of input costs and output value.

Other factors which may affect sow and piglet performance other than nutrition, are housing conditions and stockmanship. The parameters which are widely used in terms of breeding herd performance are those of litter composition, percentage piglet mortality, piglet weight, piglet and gilt growth rates and weaning to conception interval. These parameters will all have an influence on the number of piglets produced per sow per year, and thus, an influence on total output value.

2.2.2 Production in dry sow systems

In assessing dry sow housing conditions, the important parameters are those of reproduction, such as the weaning to conception interval, or for gilts, the length of time taken to reach first œstrus. Proper ovarian function is dependent on fine hormonal control of the pituitary-ovarian axis. For follicular maturation and thus, production of viable ova, it is essential that endocrine changes and their feedback control mechanisms coincide exactly (Hunter & Weisak, 1990). Any endocrine disruption, especially that of Lutenising Hormone (LH), may result in anœstrus, and it is well-documented that elevated cortisol may lead to hormonal asynchrony and reduced LH levels (Hennessey & Williamson, 1983).

There are a great many factors that may promote elevated levels of cortisol and hence result in anœstrus (Meredith, 1982) and housing conditions have been implicated in a number of studies. Both Jensen et al (1970) and Mavrogenis & Robinson (1976), found that gilts confined in tethers or stalls took longer to reach their first œstrus than group-housed gilts. Stall-housed sows have also been shown to take longer to return to œstrus after weaning than group-housed sows (Sommer, 1979, Hemsworth et al, 1982, Sommer et al, 1982). Hemsworth et al (1986a) and Barnett et al (1986) carried out a number of studies that demonstrated the effects that stocking density and group size had on expression of œstrus, successful mating and conception rates of group-housed gilts. As stocking density increased from $3m^2$ per gilt and group size decreased stepwise from 27 to 3, there was a progressive decrease in the number of gilts showing œstrous cycling. However, Cronin et al (1983) also demonstrated a tendency for anœstrus in gilts when group size was increased to over 50 per pen.

Once service has occurred, Fahmy & Dufour (1976) found that sows housed individually showed more returns to service than group-housed sows. However, other studies have found an opposite effect, most probably as a result of aggression within the group, either at mixing or during feeding (Maclean, 1969, Hansen & Vestergaard, 1984). Return to service occurs when all or most of the embryos fail to implant. If the number that successfully implant is less than about 4-5, the pregnancy will most likely not be viable and the embryos will be spontaneously aborted, resulting in a return to service.

Where litter size is small, it may be due to either failure of fertilisation, partial failure of implantation or embryonic death. These last two factors are particularly affected by stress between about days 14-21 after mating, when implantation and critical early development are taking place. Hormonal upset around this time will increase the number of embryos that fail to implant (Varley, 1981). A high incidence of mummification may also indicate welfare problems within the dry sow environment at a later stage of fœtal development.

Differences between systems may not be wholly due to the effects of the housing condition alone; there may also be an effect of stockmanship involved. Certain housing systems may mask œstrous behaviour and make identification by the stockman, difficult. Husbandry techniques such as use of service accommodation, extent of use of Artificial Insemination (AI), and timing and method of mixing sows back into the dry sow environment can all affect timing of œstrus or number of returns to service. Another very important factor is the way the stockman interacts with the stock. Aversive handling has been demonstrated to give negative effects on growth rates in poultry (Buckland et al, 1974) and pigs (Hemsworth et al, 1981, Gonyou et al, 1986) and milk yield in dairy cows (Seabrook, 1984). Hemsworth et al (1986b) also recorded decreased conception rates in gilts, and that boars took longer to reach sexual maturity, when handled aversively.

2.2.3 Production in farrowing systems

The assessment of farrowing conditions must involve measures of both sow and piglet productivity. In most cases, emphasis appears to be placed on litter composition and piglet mortality. This is unsurprising, as the current national average piglet mortality is around 11.7% (MLC, 1993), which with a further 4-8% lost through stillbirths (English & Wilkinson, 1982) represents by far the single largest 'loss-point' in terms of life and potential revenue from birth to slaughter. Piglet mortality undoubtedly has a multifactorial cause with the majority caused by overlying by the sow and piglet starvation. These two factors are inextricably linked, and are most likely to occur in the first 2-3 days of life. Other factors affecting piglet mortality (see reviews by English & Morrison, 1984, Dyck & Swierstra, 1987) include piglet birth-weight (Spicer et al, 1986), litter size (English & Smith, 1975), sow parity (Bäckström, 1973), environmental temperature (Stephens, 1971) and farrowing accommodation design (Cronin & Smith, 1992).

The latter is being studied extensively as demands for non-confinement of sows during gestation and farrowing continue to increase. There is no doubt that the design of farrowing accommodation has a very large effect on the number of piglets killed by overlying or crushing. Svendsen & Bengtsson (1982) found that 4.8% of piglets born alive were killed by crushing. Bäckström (1973) demonstrated that this figure was higher for sows farrowing in pens (5.9%) and lower for sows farrowing in crates (3.4%). However, research appears to be focusing heavily on the physical conditions in relation to piglet mortality. The success or otherwise of farrowing accommodation is most often quoted purely in terms of % mortality of liveborn. By this measure, it does appear that 'open' farrowing systems fare less well than confined farrowing systems (see Table 2.1 and reviews by Aumaitre & Le Dividich, 1984 and Fraser, 1990).

Table 2.1 Comparison of piglet losses in open and confined farrowing systems.

Author	Total Piglet Losses (%) Crates	Pens	Nº of Litters
Robertson et al (1966)	18.7	26.6	150
Glastonbury (1976)	15.9	31.3	614
Devilat et al (1971)	10.2	13.5	46
Aherne (1982)	12.7	34.6	21
Collins et al (1987)	12.0	12.4	228
Cronin & Smith (1992)	10.5	16.5	64

However, there are some studies that have found neither type of system to have an advantage, such as that by Collins et al (1987), who found mortality rates of 12% in crates and 12.4% in pens with sloping floors, and by Arey et al (1992), who found no difference in piglet mortality in the first 24 hours, for sows housed in crates, or in individual or paired open pens. A large scale study carried out by Gustafsson (1982) using data from the computerised Swedish litter recording scheme, covering over 128,000 farrowings, showed no significant differences in piglet mortality between permanent crates (18.74%), removable crates (18.80%) and open pens (18.75%). However, direct comparison between systems is difficult as there are a large number of variable environmental factors between farms that must be taken into account.

There is still a great deal of research being carried out on the modification and development of conventional crates, by such means as altering lengths and widths, but without any significant reduction in mortality rates (e.g. Curtis et al, 1989, Vermeer et al, 1993). It was found in both studies, that increasing crate size in order to allow the sow slightly more freedom did not give beneficial effects in terms of production, but instead resulted in increased mortality rates. It would thus appear that the design of crates which confer physical restriction, has reached its full potential and in order to reduce piglet mortality further, other factors should be addressed. The use of bedding has been implicated in improved piglet survivability (Vallenga et al, 1982, Aumaitre & Le Dividich, 1984, Cronin & van Amerongen, 1991) most likely because of its influence on the sow's behaviour, and improved thermal properties.

Currently, much work is being carried out on the development of alternatives to conventional crates, such as pens and circular crates (Lou & Hurnik, 1993), which allow the sow to turn round, and also communal farrowing systems (e.g. van Putten, 1988, Baxter, 1991, Rudd et al, 1992, Rantzer, 1993). Whereas piglet mortality has been shown to be slightly higher in these open systems, it must be remembered that with a greater degree of freedom for the sow, there is greater emphasis on stockmanship. This can be highlighted by a study by McGlone & Blecha (1987), in which four different farrowing systems were assessed including two types of crate, and two open systems. Management procedures were kept constant across the four treatments, and as a result, the crated systems had an average mortality of 19.4% compared with 34.8% in the open systems. Communal systems in particular present a new set of problems such as cross-suckling and desertion of the litter, and where this has occurred, mortality has been seen to reach up to 35% (Rudd et al, 1993). However, it has been shown that if management is given time to adapt to new systems, and specific problems addressed, mortality levels can be comparable with those seen in crates (Baxter, pers comm, Rudd, pers comm).

It is naive to think that the design of the 'perfect' farrowing system will magically resolve the problem of piglet mortality. Piglet mortality may be due less to the physical conditions of the farrowing environment but rather more to the anatomical, physiological and behavioural impositions placed on the sow by the dry sow environment. It has been noted by Jensen (pers comm) that when sows are kept in 'semi-natural' conditions and given total freedom during gestation and farrowing, piglet mortality due to crushing or neglect is very low. Therefore, for an effective farrowing system to be developed, there needs to be greater understanding of the effects that dry sow systems have on the ability of the sow to show or indeed to carry out maternal behaviour.

Both Bäckström (1973) and Hansen & Vestergaard (1984) have noted that a change in environment from open during gestation to confined during farrowing (or confined to open) resulted in higher mortality compared with sows going from open to open or confined to confined. This result has also been noted by Cronin & Simpson (in press) with mortality highest for sows farrowing in crates that had previously gestated in an open group. Gravås (1982) found no difference in piglet mortality for sows confined during gestation and farrowing compared with sows loose-housed during both, when weaning occurred at four weeks. However, when weaning was carried out later (six-seven weeks), the confined sows had significantly higher mortality. These results indicate the necessity for investigation into the environmental effects influencing piglet mortality.

Other production factors that can be measured when assessing farrowing systems include those of time taken to farrow, and litter composition. It has been shown that crated sows took longer to farrow, and more needed assistance (Bäckström, 1973, Hansen & Vestergaard, 1984) possibly indicating that confinement or lack of exercise may affect parturition. Bäckström (1973) and Gustafsson (1982) also noted that crated sows had an increased incidence in number of piglets stillborn. This is probably a consequence of increased farrowing time (Sprecher et al, 1975), with the increase in time of parturition likely to cause piglets to have greater susceptibility to death by anoxia. This same result was also demonstrated by Sommer et al (1982) and Cronin & Simpson (in press). Cronin et al (1993) demonstrated that sawdust applied to the floor of crates, decreased the total duration of parturition, and decreased the number of piglets stillborn, compared with crates with concrete floors. This was probably as a consequence of altered behaviour.

Another important factor for the commercial producer is that of piglet growth. Slow piglet growth means later weaning and a lower number of litters per sow per year. There appears to be little or no difference between sows farrowing individually, whether in crates or pens (e.g. Collins et al, 1987), but a number of studies have seen a disadvantage in piglet growth rate in communal systems. Rudd et al (1993) have shown that the piglets of sows farrowing in conventional crates grow faster than piglets in two communal systems and are heavier when weaned at the same age. Sinclair et al (1993) have also shown reduced weight gain in piglets for the first week after entry into a communal housing system during lactation. This is probably as a consequence of two factors. Firstly, there may be a degree of cross-suckling, and where there are piglets of differing age and size, competition may result in smaller piglets not gaining access to sufficient milk. Another problem is temporary desertion of the litter by the sow. Jensen (1988) has demonstrated that, given the option, sows will spend time away from the litter. Some communal systems incorporate areas accessible to the sow only, and certain sows may spend too much time in these areas.

Where this occurs, it has been shown that piglet weight gain is influenced by the amount of time the sow is absent from the piglets (Houwers et al, 1992).

Weight gain may also be influenced by other factors such as initial birth weight and litter size. Birth weight is correlated with litter size, and thus the larger the litter, the smaller the piglets are likely to be at birth. However, there is also likely to be a greater variation of individual birth weights. Consequently, where there is greater competition for milk supplies, initial differences in piglet size may lead to within-litter variation in weight gain, where smaller piglets are deprived of sufficient milk. This competition can be increased where cross-fostering is practised, and it has been shown that fostered piglets have retarded growth rates (Horrell & Bennett, 1991).

Birth weight can obviously be greatly influenced by nutrition during gestation. However, the dry sow housing condition has also be shown to affect piglet weight. Den Hartog et al (1993) have shown that sows housed in groups during gestation gave birth to piglets with lower birth weight than stalled or tethered sows. This result could be explained in terms of the social competition known to exist within a group of sows. A study carried out by Mendl et al (1992) demonstrated that within a group of sows, there were three distinct social strategies, and that sows in the 'high success' and 'passive avoiders' groups gave birth to a greater total weight of piglets, than sows in the 'fight back but usually lose' group which were, in effect, subjected to the greatest social stress.

Production figures can be a useful first indicator of the welfare of stock within a housing system. However, it must be remembered that whole herd figures can mask individuals with severe welfare problems and that there are a great number of previous and current environmental factors that must be taken into account, before an objective evaluation can be made, of a specific housing system.

2.3 Behavioural indicators

2.3.1 Introduction

The study of behaviour as an indicator of welfare is very appealing due to the complete absence of invasive technique, which can influence results where physiological measures are involved. Determination of altered or abnormal behaviour patterns can only be achieved with a sound knowledge of the species' normal behaviour patterns, i.e. the behaviour patterns of feral or free-ranging conspecifics.

A great deal of study has been carried out on farm animal species, and thus, this review will refer mainly to research carried out on pigs, and more selectively, that carried out on sows during pregnancy and farrowing.

Work on free-ranging domestic pigs kept in a semi-natural enclosure, has highlighted the complexity and range of behaviours that pigs carry out when given the opportunity (Jensen, 1986, 1988, Jensen & Redbo, 1987, Jensen et al, 1987). These include social, reproductive and maternal behaviours, together with individual components such as feeding, locomotory, exploratory, eliminative and resting behaviours. Commercial housing systems do not confer the freedom of natural conditions, and therefore influence and restrict a pig's behaviour to a lesser or greater degree, depending on the type of system used.

2.3.2 Behaviour within the dry sow environment

As stated in Chapter 1, there is a wide variety of dry sow housing systems in use in commercial pig production. Each housing type will affect the behaviour repertoire of the sows kept in it, and this effect may be one of modification of normal behaviours, such as alteration of time budgets, or manifestation of abnormal behaviour, such as occurrence of stereotypies. The latter is especially prevalent in systems that offer a barren environment, such as those afforded by close confinement in stalls or tethers. Pigs are intelligent, inquisitive animals with a large learning capability and elaborate social behaviour. If placed within a barren environment, they often become frustrated with the lack of stimuli and will show behavioural modification. This most often takes the form of occurrence of stereotypic behaviours such as sham- or vacuum-chewing, bar-biting and drinker manipulation or increased inactivity. Numerous studies have demonstrated that stereotyped behaviour occurs with high frequency among stalled or tethered sows (see Table 2.2).

Table 2.2 The percentage time that stalled and tethered sows spend engaged in stereotypic behaviour.

Authors	Period	Amount
		Stalls
Broom & Potter (1984)	during 8 hrs post- feeding	11%
Blackshaw & McVeigh (1984)	during 24 hrs	10-14%
Jensen (1981)	during time active	22%
		Tethers
Carter & English (1983)	during 2 hrs	1.8-28%
Bengtsson et al (1983)	during 9 hrs of daytime	15%
Blackshaw & McVeigh (1984)	during 24 hrs	14.5-29%
Cronin & Wiepkema (1984)	during daytime	up to 80%

The mechanisms involved in the development and continuations of stereotypic behaviours have been under discussion for some time. It has been debated as to whether they are a method of coping or whether they are present as a consequence of coping; i.e. are they causative or symptomatic. The possibilities are discussed in detail by Mason (1991). A popular idea is that stereotypies occur in response to chronic stress in order to decrease any adverse effect that the stressor may have on the individual. Thus, "they can serve to increase total sensory input in a barren environment but produce a more predictable input in a disturbing situation" (Fraser & Broom, 1990).

The presence of stereotypies is sometimes associated with a reduction in physiological indicators such as circulating corticosteroid concentrations (in pigs, Dantzer & Mormède, 1981, 1983) and heart rate (in children, Soussigan & Koch, 1985). There is also evidence of a link with endogenous opioids (ß-endorphin). Cronin et al (1985), demonstrated that injecting naloxone (a ß-endorphin blocker) into stereotyping sows, caused cessation of stereotypic behaviour. It is possible that stereotypic behaviour induces opioid release which has an analgesic effect on the brain. However, the relationship may be temporal rather than causal in nature, or indeed be reversed (Ödberg, 1978). This analgesia has been demonstrated in pigs using the tail-flick test (Rushen et al, 1990).

Feed restriction (Terlouw et al, 1991) and influence of neighbours (Appleby et al, 1989), rather than physical restriction, have been shown to be major factors in the development of stereotypies. Once developed, changing diet can have an effect on the incidence of stereotypic behaviour; addition of roughage such as unchopped straw can reduce time spent stereotyping (Fraser, 1975), as can increasing the sow's daily ration (Appleby & Lawrence, 1987). Stereotypic behaviour is not exclusive to confined sows, and has also been observed in loose-housed sows, especially where availability of feed is restricted (Terlouw et al, 1991).

Clearly there are great differences between individuals in the ways in which they attempt to cope. It can be stated generally, that there is a much greater incidence of stereotypic behaviour in confined sows compared with loose-housed sows. However, there are also large differences among confined sows. If engaging in stereotypic behaviour is a coping mechanism, it would appear that there is an alternative coping mechanism, namely that of inactivity or apathy (van Putten, 1980, Fraser & Broom, 1990). It has been reported that stalled or tethered sows are more inactive than those kept in a group system (Ekesbo et al, 1978, Jensen, 1979, 1980, 1981, Gravås, 1982, Carter & English, 1983), but the reverse has also been noted. This may be due to a differential effect of parity, stage of pregnancy and extent of lameness (Cariolet & Dantzer, 1985).

Thus, looking at degree of activity alone can be a poor indicator of welfare if there is more than one way of coping with the boredom or frustration induced by the confinement of a sow stall or tether, as suggested. Some sows may become inactive or "depressed", with associated unresponsiveness (van Putten, 1980, Wiepkema et al, 1983), whereas others may be very active but show stereotypies as the activity (Broom, 1987). As stated earlier, confined sows may engage in stereotypic behaviour, in order to produce a state of 'self-narcotisation' or analgesia, which leads to lowered responsiveness (Ödberg, 1978, Cronin et al, 1984, Dantzer, 1986). With both strategies, the end result appears to be a lack of responsiveness. Thus, sows must be studied individually and their responsiveness assessed precisely, for example, by the tail-immersion test (Dantzer et al, 1986). Broom (1986b, 1987) has shown that, in general, stalled sows are less responsive than group-housed sows, to the presence of a human and to water being tipped on their backs. However, where food was used as a stimulus, there was no difference between housing systems, perhaps highlighting the importance of the feeding event for sows kept in a barren environment.

Another aspect of behaviour modification that can occur in confined systems is that of abnormalities of basic movements, such as standing and lying (Fraser & Broom, 1990). This will be discussed in detail later, in relation to behaviour in farrowing conditions, where difficulties in carrying out these movements may influence the maternal behaviour of the sow and thus have consequences for piglet mortality.

When farmers are questioned on the disadvantages of group-housing systems for sows, they will invariably comment on the problem of aggression and bullying. Even in stalls and tethers, inter-neighbour aggression can be high (Vestergaard & Hansen, 1984, Barnett et al, 1987), but the physical consequences for the sow receiving the aggression are negligible, due to the lack of opportunity for physical contact.

In a group situation, however, aggression can have a severe effect both in terms of physical injury, and also on production. This aggression is due to the establishment and maintenance of a social hierarchy. These problems of aggression are exacerbated when sows are reintroduced after farrowing, and the hierarchy then has to be re-established. The consequences of this aggression have been discussed earlier. Where aggression is prevalent, the welfare of subordinate sows can be poor.

Research by Mendl et al (1992) has shown that there is not a simple dominant-subordinate composition within the social hierarchy of a group. Instead, it comprised of three sub-populations, namely: i) high success sows, which won more agonistic social encounters than they lost, ii) middle success sows, which lost more than they won, and iii) low success sows, which lost all encounters (see Figure 2.2). A similar distribution of success has also been noted in rats (Fokkema, 1985), and it has been proposed that the low success animals appear to "opt out" of aggressive conflict and thereby reduce the amount of aggression directed at them. Thus, there appear to be two methods of coping with social aggression in sows; the first is to compete with the aim of becoming a top ranking animal, and the second is to actively avoid confrontation and thus minimise aggressive social encounters. It has also been shown that the social status of an individual sow may have consequences on some aspects of physiological function and on production (Mendl et al, 1991).

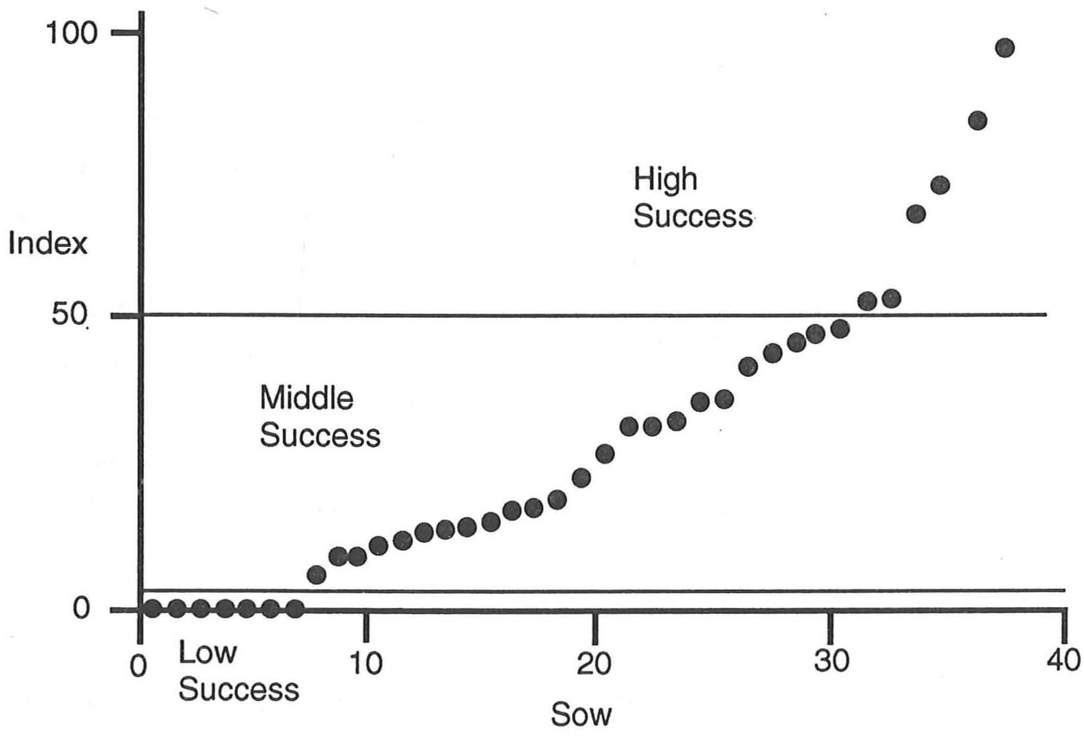


Figure 2.2 Success indices for group-housed sows (from Mendl et al, 1992)

Individuality in behavioural response of gilts to social and non-social challenges has been investigated by Lawrence et al (1991). It was found that individuals responded consistently to a variety of non-social challenges but non-consistently in certain elements of response to social challenge. However, Hessing et al (1993) have shown consistency among piglets in behavioural responses to both social and non-social challenges.

Another factor that can have a very large influence on aggression, is that of feeding method. Present methods of feeding group-housed sows include;
i) individual feeding stalls, into which the sow can be shut during feeding.
ii) electronic sow feeder systems (ESF), which deliver computer-controlled amounts of feed to a single sow.
iii) trickle feeders, which feed all sows simultaneously and slowly to prevent dominant sows from eating their ration quickly, and displacing slower eating sows.
iv) dump feeders, which again feed all sows simultaneously, but quickly in a single delivery onto the floor.
Methods (i) and (ii) have the advantages of being able to feed sows an amount suited to individual requirements, without danger of displacement by dominant sows, but can be expensive in terms of labour costs. Methods (iii) and (iv) allow simultaneous feeding which is beneficial (Edwards, 1985, Whittemore, 1993), but without control of individual rations. However, all methods will affect the amount of aggression prevalent within the housing system.

Single feeding stalls, which can be shut, allow sows to eat without fear of attack from the rear. However, as with stalls and tethers, there can be non-physical aggression from neighbouring sows, which can make feeding a stressful experience. ESF systems have undergone extensive development since introduction as a result of numerous trials (Lambert et al, 1983, 1984, 1985, Edwards, 1985), and most current designs are situated away from the lying area and offer entry from the rear, into an all-enclosed feeding environment, and a forward exit, inaccessible to other sows. These modifications have removed many of the sources of aggressive behaviour, but the problem of only one sow being able to feed per feeder, at any one time is insurmountable.

Therefore, there is invariably a "build-up" of sows wanting entry to the feeder, especially at the time the computer control cycle switches over for the next feeding period. Consequently, a large number of agonistic social encounters occur at this time, as the most dominant sows are regularly among the first to seek feeder entry.

Work by Hunter et al (1988) demonstrated a positive correlation between feeding order and social hierarchy, at least for the higher placed members of the hierarchy. Lower down, the relationship tends to break down, perhaps due to non-feeding visits made by higher ranking sows. Positive correlation between feeding order and parity was also shown, probably as a consequence of greater feeder-use experience. It has been noted by Mendl (pers comm) that the low rank sows will wait and feed when activity around the feeder is at a minimum with entry unchallenged by higher ranking sows.

A study by Weber et al (1993) has shown that if the number of daily feeding cycles is increased to two, there is an upsurge in aggression and increase in the total time queuing for access to the feeder station from 34.8 minutes to 64.9 minutes. There were significantly higher levels of aggression among sows in the ESF house compared with sows housed in groups with single feeding stalls and simultaneous feeding.

Trough or stall feeding systems that give each sow access without being shut, have in the past presented problems of fast eaters finishing their ration and displacing slower eaters. This problem can now be alleviated by use of a "trickle-feed" system, which delivers food at a slow rate over 10-15 minutes, thus ensuring sows stay at their stall for the full time that food is present. Systems which deliver food direct onto the floor or into straw have made a recent re-emergence though they have been shown to be a major cause of aggressive behaviour, leading to injury and lack of food for sows low in the social hierarchy, i.e. causing poor welfare for certain individual sows (Csermely & Wood-Gush, 1986).

A study by Edwards et al (1993) compared sows housed with three different feeding systems; a floor feeding system, an *ad libitum* feeding system and individual feeder stalls. It was found that the floor feeding system gave rise to the highest levels of aggression and body damage. Low ranking animals in a mixed parity group were particularly disadvantaged and were deprived of sufficient food. Within a group of gilts of similar size, this disadvantage was less conspicuous. Providing feed *ad libitum* did reduce aggression, but there was a continued problem of liveweight gain and of feed costs.

Thus, the type of dry sow housing system can have a marked effect on the behaviour of sows and their subsequent welfare, and it is important that the group-housed sows are not all identified as a single typical population, i.e. individuality must be accounted for.

2.3.3 Behaviour within the farrowing environment

A sow's behaviour at farrowing, is subject to the constraints placed upon her by the housing system in which she farrows. All farrowings in the commercial pig industry occur in a restrictive environment, whether this is an open pen, or more likely, a conventional crate. This restrictive environment greatly decreases the sow's ability to show her natural behaviour around the time of parturition. Studies on free-ranging domestic pigs have shown a complex repertoire of maternal behaviour. Jensen (1988) has proposed that the maternal behaviour can be divided into six distinct parts; (i) isolation and nest site seeking, (ii) nest building, (iii) farrowing, (iv) nest occupation, (v) social integration, and (vi) weaning.

2.3.3.1 Pre-partal behaviour

Stage (i) occurs about 48-24 hours before parturition, when the sow separates herself from the herd to find a suitable secluded nest site. The importance of this isolation can be gauged by the distances that sows are willing to walk, reported to be between 2.5 & 6.5 kilometres (Jensen, 1986, Jensen et al, 1987). Arey et al (1992) also noted an increase in aggression between sows housed indoors in pairs as farrowing approached, perhaps highlighting this requirement of social isolation. Modification of these paired pens, to give a greater degree of visual isolation, resulted in a reduction in incidence of this aggression as did pairing sows with familiar penmates. Outside, Jensen (1986) noted that the sites were often situated away from the usual "home range" of the sow, and were often chosen to provide a degree of both vertical and horizontal protection. This preference for farrowing sites that offer some degree of vertical protection has been demonstrated indoors by Hunt & Petchey (1989) and Phillips et al (1991).

Of the commercial farrowing systems currently in use, single open pens (e.g. Phillips & Fraser, 1993, Schmid, 1992) would seem to offer the best environment with regards to sow preference for this stage of maternal behaviour. They confer social isolation and a degree of vertical protection not seen in commercial crates. For communal systems such as those of Baxter (1991), Houwers et al (1992) and Rudd et al (1992), it would perhaps be preferable if preparturient sows were shut into the individual farrowing areas until farrowing has occurred. This would give pre-farrowing isolation, which can then be coupled to time away from the litter for the sow, and also social integration of litters prior to weaning, which are important post-farrowing. For outdoor systems, farrowing arks would appear to meet most of the preparturient sow's requirements, and use of a fender can confine the litter but allow the sow to come and go alone during the first couple of weeks post-farrowing.

Stage (ii) or nest building occurs during the last 24 hours prior to parturition, and consists of vigorous rooting of the chosen site followed by gathering of a large quantity and variety of flora (Jensen, 1989). A single nest of a free-ranging Duroc sow in Brazil provided with straw, was seen to contain 255 kilograms of mostly other plant material, the majority of which was up-rooted by the sow with considerable effort (Zanella & Zanella, 1993). Thus, the sow is highly motivated to perform nest-building behaviour and this is seen in all housing conditions. Pre-constructed nests such as the Profort farrowing nest (Higginson, 1989) have been marketed but it has been shown that the provision of a pre-constructed nest for sows farrowing indoors does not lessen the motivation to build (Arey et al, 1991), and sows will prefer to construct their own. They also prefer to construct a nest on soil rather than concrete, if given the option (Hutson & Haskell, 1990, Arey et al, 1991). Straw will be utilised for nesting material if available (Widowski & Curtis, 1990), but the observations of Zanella & Zanella (1993) show that it is probably not the most preferred material.

With this motivation for nest-building being so strong, any design of farrowing accommodation that confers restriction will significantly influence the sow's maternal behaviour during the immediate pre-farrowing period. All sows, independent of accommodation type, show an upsurge in nest-building behaviour in the last 24 hours prior to parturition (Vestergaard & Hansen, 1984, Lammers & de Lange, 1986, Widowski & Curtis, 1990) but the precise extent and nature of behaviour shown is dependent on accommodation type. Hansen & Curtis (1981) demonstrated that sows housed in crates, stood or sat up more often than sows housed in pens during the last 48 hours prepartum, and that the addition of straw to both systems had no effect on any prepartal behaviour. Cronin et al (1993) however, reported that provision of sawdust to young sows housed in farrowing crates on concrete, appeared to stimulate pre-partum nest-building-type behaviour, such as rooting/pawing/nosing and that this in turn may have served to reduce the duration of parturition and increase the survivability of the litter. Older sows were unaffected by presence of sawdust, perhaps indicating the influence of previous experience with nesting material.

Heckt et al (1988) reported similar differences in activity with gilts housed in three different farrowing systems, namely crates, pens and "turn-around" crates. All gilts showed an increase in pawing/rooting behaviours and in the number of postural changes as farrowing approached, but gilts housed in standard crates stood up more frequently than those in the systems which allowed more freedom of movement. The suggestion is that sows housed in crates become frustrated in their inability to walk and nest-build effectively, and that this frustration may manifest itself as an increased frequency of standing and lying.

Vestergaard & Hansen (1984) also demonstrated increased frequency of standing and lying for crated sows, but with the addition of an effect of dry sow housing conditions. Crated sows which had previously gestated in an open environment appeared to show the greatest amount of what was described as "restlessness", compared with three other treatments.

Vestergaard & Hansen (1984) concluded that nest-building appeared to be dependent on internal factors, a view shared by Heckt et al (1988), who reported "striking similarities" in nest-building behaviour between three different experimental systems. Lending credence to this view, is the fact that Heckt et al (1988) used gilts in their experiments, i.e animals with no previous experience. The study by Cronin et al (1993) where young sows' behaviour was modified by sawdust whereas older sows' behaviour was not, would seem to suggest that previous experience of environmental factors such as presence of nesting material, will greatly influence nest-building behaviour at subsequent farrowings. Jensen (1988) also noted that environmental factors such as temperature affected the nest-building of free-ranging sows, and proposed a form of feed-back regulation on the control of this nest-building behaviour. There was also positive correlation between the amount of nesting material gathered and parity number, indicating influence of experience. Thus, it would appear that internally driven nest-building behaviour may be modified by external factors.

Stage (iii) - farrowing - can also be affected by the housing system, as has been mentioned above, in the section on measures of production. A number of authors have reported that farrowing duration is longer for confined sows compared with loose-housed sows (Bäckström, 1973, Hansen & Vestergaard, 1984) and that this is probably as a consequence of lack of exercise or activity in the few days prior to parturition. Cronin et al (1993) have demonstrated that increasing activity by stimulation of behaviour using sawdust as a substrate, results in decreased farrowing duration.

Confinement during farrowing itself may not have many detrimental effects. The sow is unusually passive for an ungulate, and once parturition is underway, she rarely carries out postural changes. She does not get up to help the neonates from their foetal membranes and the umbilical cord is normally torn when the piglet moves around to the udder. Jensen (1988b) proposes that this passivity may be due to the fact that the sow gives birth to a large number of precocial young, and that to engage in maternal behaviour individually as the piglets are born, may place them at unnecessary risk of accidental crushing. Once the whole litter has been born, however, her subsequent maternal behaviour will again be subject to constraints imposed by the housing system.

2.3.3.2 Post-partal Behaviour

During Stage (iv) or "nest" occupation, maternal behaviour has a very complex organisation mainly revolving around the suckling event. In a free-range situation, the sow and piglets stay away from the rest of the herd for at least the first week post-partum (Jensen, 1988). During the first one or two days, the sow forages very little and stays in close proximity to the nest site. Later, she leaves the nest for longer periods and forages further away, and eventually rejoins the herd for morning feeding, on average seven days after parturition. The litter remain using the nest for a further two to three days, until it is abandoned around day nine. Thereafter, the litter is gradually introduced into the herd.

The behaviour of the sow and litter during this stage of nest occupation probably establishes the sow-offspring recognition that is important once social integration has occurred (Jensen & Redbø, 1987). As stated, an important aspect of mother-offspring behaviour is that of the suckling event. Immediately after parturition, the piglets make their way round to the udder, possibly in response to both auditory and olfactory cues, and suckle colostrum which is continuously available for a few hours post-partum. After about 10 hours, milk let-down shows periodicity (Lewis & Hurnik, 1985), lasting approximately 10-25 seconds every 40-60 minutes. Let-down is preceded by characteristic grunting from the sow (Whittemore & Fraser, 1974), which is recognised by the piglets and ensures that they are ready on the teats when milk is delivered. There is some evidence that massaging of the udder by the piglets influences milk production and timing of let-down by stimulating oxytocin release (Algers, 1990).

For the piglets, milk let-down is obviously important for survival, and there is intense competition for teats at this time. With the period of milk let-down being short and simultaneous for all teats, it is ensured that all piglets have access to milk at the same time and the risk of starvation for the smaller piglets is reduced. However, there may be variation in productivity between teats, and it has been shown that piglets have a preference for the more productive teats (McBride, 1963, Jeppesen, 1982a) and also for anterior teats. These preferences lead to formation of a "teat-order", whereby each piglet attempts to suck exclusively from a specific teat (McBride, 1963, Hemsworth et al, 1976, Fraser et al, 1979). The teat-order is quickly developed during the first day of life, and there is a tendency for the larger, heavier piglets to win competitive interactions, and thus become attached to the more productive teats, leaving the smaller, lighter piglets at greater risk of mortality due to starvation-induced weakness.

There is some evidence that teat order is maintained by olfactory cues placed on the teat by the piglet (Jeppesen, 1982b). "Deodourisation" of an artificial sow twice daily, caused disruption and resulted in a variable teat-order. Disruption of the teat order can also occur when cross-fostering is carried out as part of normal husbandry practises by the stockman. Horrell & Bennett (1981) demonstrated that this disruption was followed by retardation of growth of the fostered piglets, and that this retardation was greater when their preferred teat was already in use by a resident piglet. It has also been reported that fostering disturbs the sow, causing her to become aggressive towards fostered piglets and to increase the number of suckling episodes which do not result in milk let-down (Horrell, 1982).

Cronin & Smith (1992a) have shown that the farrowing system can influence the duration of suckling behaviour of both sow and piglets, without alteration of suckling bout frequency. Sows housed in crates spent less time performing, and had shorter bouts of, rapid pre-suckling grunts. Consequently, piglets spent less time engaged in, and had shorter bouts of, rapid sucking movements. However, this did not have any effect on piglet weight gain. Another study looked at the effect of bedding (straw) on these two treatments, and it was shown that the addition of straw to both crates and pens, increased duration of rapid pre-suckling grunts compared with the un-strawed systems (Cronin & Smith, 1992b). Sows housed in crates without bedding, spent more time lying sternally, and less time in lateral recumbency thus restricting access to the udder. There was also a tendency for sows in the straw-added treatments to engage in more piglet-oriented behaviours, and piglet weight gain was significantly greater.

Stage (v) of maternal behaviour for free-ranging pigs is that of social integration. As stated earlier, pigs have a complex repertoire of social behaviour, which begins development immediately after birth with the formation of the teat-order. While the piglets remain in the "nest", which for individually housed sows is until weaning, there are extensive piglet-piglet and sow-piglet interactions occurring. The sow-piglet interactions are important for the formation and maintenance of the mother-offspring bond. Naso-naso contact between sow and litter is most often observed immediately post-suckling (Whatson & Bertram, 1983) and is thought to reinforce this bond. The bond is also maintained via vocal communication and olfactory cues (Horrell & Eaton, 1984, Horrell & Hodgson, 1992a, 1992b) which becomes especially important once the sow and litter have moved into a group situation.

Free-range sows begin integrating their litter into the herd towards the end of the second week (Jensen, 1988). This allows time for family bonding to become complete before introduction to other litters. This introduction results in a shift of social interactions away from litter-mates towards other piglets of a similar age (Petersen et al, 1989). The frequency of these interactions gradually decrease to a steady low level after about eight weeks. These results have important consequences for the design of group farrowing accommodation. It would seem to be appropriate to allow mixing of litters prior to weaning, but not before about 14 days post-partum.

One aspect where sow-piglet communication is very important, is when the sow lies down or stands up. During these periods, the piglets are at risk of crushing by the sow, which has been shown to be the major cause of piglet mortality. Jensen (pers comm) has noted that prior to lying down, the free-ranging sow communicated her intentions both vocally and physically, ensuring that the litter was away from the lying area. Blackshaw & Hagelsø (1990) have also noted that sows housed in loose pens carried out specific behavioural sequences prior to lying. Whereas Jensen (1988) has reported high piglet mortality rates, the majority were due to environmental factors such as adverse weather, and few were as a direct result of crushing. Therefore, any factors which cause difficulty in carrying out the essential behaviours of standing and lying, or indeed restrict sow-piglet interactions beforehand may have consequences for the welfare of both the sow and her litter.

Farrowing crates will affect both of these components. The sow has no opportunity to turn and inspect the lying area, and little opportunity for physical interaction with her litter. Also, work on the lying behaviour of sows in farrowing crates has highlighted a degree of difficulty of movement, mostly due to the crate design (Baxter & Schwaller, 1983). They found that the majority of crates in the UK were designed to fit the static space requirement of sows, but failed to meet the dynamic requirements of sows whilst lying and standing. This was also the case in the U.S. (Curtis et al, 1989). There is therefore no doubt that confinement of sows in farrowing crates restricts standing and lying. However, what is unknown is the extent to which dry sow systems may further influence these behaviours.

Long term confinement has been shown to affect muscular fitness in other species. Work by Herlin (1990) and Krohn & Munksgaard (1993) on tied and loose dairy cows, has found significant differences in the times taken for lying down, between the two groups. Tied cows took longer to lie down, suggesting difficulty of movement for cows with no ability to exercise. Tied cows also showed a greater incidence of interruptions to the action.

Confinement also decreased the time spent lying on the side, in dairy cattle (Herlin, 1990, Krohn & Munksgaard, 1993) and in crated veal calves (de Wilt, 1984), which may lead to disturbed sleeping patterns. It is therefore probable that long-term confinement of dry sows will result in similar problems of muscular fitness.

The final stage of maternal behaviour according to Jensen (1988) is that of weaning. In effect, natural weaning started early on in lactation. The frequency of suckling declined gradually from the first week, and the number of sucklings terminated by the sow increased perhaps indicating that the sows became less inclined to nurse (Jensen et al, 1991). The number of piglets missing from suckling also gradually increased and weaning was completed on average around 17 weeks post-partum (Jensen & Stangel, 1992). Götz (1991) compared these results with sows in crates, and showed that between the first and fourth weeks post-partum, sows in crates maintained their suckling frequency. He attributed this to the constant "closeness" of the litter, and the lack of an enriched environment. It was noted that there was an decrease in the amount of time spent lying laterally recumbent, which has been proposed by De Passillé & Roberts (1989) to be a form of avoidance behaviour.

The timespan of weaning seen in the semi-natural environment, is not practicable in a production environment. However, it does highlight the problems faced by piglets on a commercial unit, where they may be weaned abruptly as early as three weeks of age and housed with piglets from other litters. Group housing at farrowing can alleviate some of these problems, by allowing sows access to a communal area without the piglets (e.g. Rantzer, 1993) and by introducing litters to each other before weaning (e.g. Baxter, 1991).

It important that the assessment of farrowing accommodation takes account of the behaviour of both sow and litter, and that reference is made to any confounding factors caused by the previous dry sow environment.

2.4 Physiological indicators

2.4.1 Introduction

Possible physiological measures include either direct measurement of the components of the SA and the HPA axes or measures of activity of their target organs. One of the most often used parameters in recent years has been the measurement of cortisol, an adrenal cortex product. There has also been an increase in heart rate measurement, as monitoring equipment has developed. This section will mainly review work using these two physiological parameters.

2.4.2 Adrenal measures

It has long been implied that high cortisol concentrations mean high stress. This is because during stress, extra energy reserves may need to be mobilised and this is brought about in the short term by increased activity of the sympathetic nervous system and adrenal medulla, and in the longer term by an increase in activity of the adrenal cortex. However, there has been disparity of results highlighted in detail by Rushen (1991). Many researchers have failed to appreciate that blood sampling, a distressing invasive technique, can affect results over the short-term. Also, cortisol secretion in the intact animal is episodic in nature, and single-point samples are of little use, and in fact, adrenal activity may increase in situations that are not obviously stressful, e.g. courtship, mating and active food acquisition.

In response to these criticisms, the ACTH challenge test was developed to show the maximal cortisol secretion levels attained following dexamethasone (inhibitory) and ACTH (stimulatory) action on the pituitary and adrenal cortex respectively. This can then be taken as an indicator of recent adrenal cortex activity in relation to stress. In order to minimise stress during sampling, the use of salivary measures as an alternative to plasma measures of cortisol has been developed and validated (Parrott et al, 1989, Parrott & Misson, 1989). Cortisol can be measured in saliva using an enzyme-linked immunosorbent assay (ELISA) (Cooper et al, 1989).

Factors known to affect cortisol levels include housing system (both dry sow and farrowing), feeding system, quality of handling and breed. A number of studies have looked at the effect of dry sow housing system, and it has been shown that sows kept in tethers generally had a greater baseline plasma cortisol concentration and a greater maximal response to the ACTH challenge test than those kept in a group system (Barnett et al, 1984) or in stalls (Barnett et al, 1985), though others have found no difference between stalls and tethers (McGlone et al, 1993). Work by Mendl et al (1992) has shown that within the group-housed, ESF sows, there were three separate social strategies, as discussed earlier, and the sows which fought and lost most often, showed the highest basal cortisol levels and also had the highest cortisol response to ACTH. This difference has also been reported by Nicholson et al (1993), who found higher cortisol levels in sow of intermediate social status. Again, it highlights the danger of treating group-housed sows as an homogenous population.

In the farrowing situation, sows farrowing in crates were shown to have higher cortisol levels than sows farrowing in open pens (Cronin et al, 1991), but only on the day of introduction to the systems, and on day 28 of lactation. Lawrence et al (1993) did a similar experiment using gilts, and reported that cortisol levels in crated gilts were higher over the immediate pre-farrowing period, which may indicate that cortisol responses to confinement at this time are modified by experience. Handling can also affect cortisol levels; pigs subjected to aversive handling techniques show fearful behaviour towards humans, and most have elevated cortisol levels when compared with pigs handled positively (Hemsworth et al, 1981, 1986b, 1987). There are breed differences in cortisol responses to confinement, with Meishan and Meishan crosses having higher responses than Yorkshire pigs (Bergeron et al, 1993) but no differences were found between Meishan and Large White sows farrowing in pens (Meunier-Salaün et al, 1991).

2.4.3 Heart rate measures

The idea and method of using heart-rate as an indicator of stress, i.e. as a measure of sympathetic arousal, is not a new one but it is becoming more widespread and easier to achieve as technology improves. Development of highly portable measurement devices for individuals such as athletes, has improved reproducibility and lengthened the time of measurement without cumbersome equipment compromising the results. The early research utilising heart-rate involved the study of energy expenditure or heat production, e.g. in sheep (Webster, 1967), in calves (Holmes et al, 1976), in hens (Yamamoto, 1986) and in man (Dauncey & James, 1979), and was carried out in conjunction with calorimetry.

Later, heart-rate monitoring was developed as an aid to behavioural study both in natural conditions and also enforced environments and the relationship between heart rate and behaviour has been demonstrated in humans (Smith & Kampine, 1980), sheep (Baldock et al, 1988) and chicks (Potter, 1987), where heart rate has been seen to differ according to posture and locomotion with modification by specified activities. MacArthur et al (1979) recognised its usefulness in determining the stresses involved in survival in the wild, when it was applied to free-ranging bighorn sheep. Changes in heart-rate with growth and activity in white-tailed deer fawns has also been studied (Jacobsen, 1979). The possible use of heart-rate measures as a determinant of stress under unnatural conditions is a fairly new concept. Syme and Elphick (1982) used telemetry to illustrate that changes in heart-rate are closely related to behaviour in sheep. This idea was further developed by Baldock (1985).

Effects of human husbandry practices have also been demonstrated in farmed red deer by Price et al (1991). Whereas approach by a familiar handler was greeted with a rise in heart-rate, approach by an unfamiliar handler greatly increased this rise. Work by Baldock et al (1988) has identified heart rate to be influenced by three major factors in sheep, namely i) behaviour, ii) season, and iii) individual identity. The influence of individual identity and behaviour could easily be seen to apply to pigs but the effect of season could be open to question. Pigs on modern indoor breeding and rearing units do not undergo the same temperature and daylength variations as do animals out of doors. There may be some variation in these factors but to a much lesser degree due to maintenance of a controlled environment using heating or ventilation and a time-switch lighting regime. However, it could be expected that some difference in heart-rate between mid-summer and mid-winter may be demonstrable, especially in outdoor herds. The other influence of season is on the physiological status of the animal. Sheep are seasonally polyœstrous and undergo only one gestation per year. Pigs are now polyœstrous all year round and for production purposes, undergo ideally over two gestations per year. Thus, any measures of heart-rate would have to take into account the effect of stage of parity.

Heart-rate monitoring in pigs has presented its own particular set of problems and therefore has only been developed as measuring equipment has been improved. Due to body composition (i.e. fat layers), signals from heart muscle have been hard to measure without fading or interference from other muscular activity. Schouten & Wiepkema (1991) have been involved in linking heart-rate to stereotypy in sows. It has long been thought that engaging in stereotyped behaviour is a form of coping mechanism and may involve self-narcotisation by endogenous opioids. Schouten & Wiepkema (1991) have demonstrated that sows which show a high degree of stereotyping have a lower mean heart rate after feeding (when stereotypy is most pronounced) than low stereotyping sows. Specific responses to feeding have been reported in calves, lambs, kids, dogs (all Bloom et al, 1975), cats (Matsukawa & Ninomija, 1987) and pigs (Schouten et al, 1991), with all species showing a rise in heart rate when feeding occurs. Schouten et al (1991) also demonstrated a difference in response between confined and non-confined sows.

Whereas a few years ago, physiological measures tended to involve invasive techniques, which could affect the final results, recent developments have made such measures easier and therefore of greater applicability.

2.5 Immunological and disease indicators

As stated in Chapter 1, it is now well-established that stress can have an immuno-suppressive effect. Stressors such as size and composition of social group (in mice and rats, Peng et al, 1989, Steplewski et al, 1987), separation (in primates, Coe et al, 1989, Reite et al, 1981), restraint (Steplewski & Vogel, 1986), transport (Murata, 1989), noise (Monjon & Collecter, 1977) and the general effects of housing and handling (Giraldi et al, 1989) have all been shown to affect immunity.

All these factors are likely to be encountered by a pig on a commercial unit during its lifespan and the first indication of immunosuppression for the producer is likely to be presence of disease. For sows, a number of studies have implicated the effects of housing conditions, particularly confinement, on disease incidence. Bäckström (1973) recorded a higher incidence of MMA among sows farrowing in crates and a greater total sow morbidity at farrowing compared with loose-housed sows. Hansen & Vestergaard (1984) noted a higher incidence of MMA for sows tethered at farrowing, especially if they had previously gestated in an open environment. Confined sows have also been shown to be more prone to urinary diseases (Madec, 1984, 1985, Tillon & Madec, 1984) but this may be as a consequence of altered lying, drinking and eliminative behaviours rather than increased susceptibility due to immunosuppression.

A factor that may influence lying and standing behaviour of confined animals is that of lameness. Lameness is a symptom of disease rather than a disease itself, and can occur as a consequence of genetic leg weakness, physical injury or infection. Infection, both direct and as a consequence of physical injury, may be influenced by immunocompetence, whereas genetic causes are not. Krohn & Munksgaard (1993) noted a greater incidence of hock inflammation in tied dairy cows and lameness has also been reported as more frequent in confined sows (Bäckström, 1973, Tillon & Madec, 1984), but the causes of this lameness have not been specified. Any housing system that increases the chance of traumatic injury will increase the risk of infection, and this may be via poor flooring (Smith & Robertson, 1971) or in confined systems, as a consequence of lack of exercise (de Koning, 1983). Lameness will be discussed further in Section 2.6.

Whereas the ultimate result of immunosuppression may be increased disease incidence, disease will only occur if the animal is exposed to an infectious agent, and large numbers of animals may be needed to show any differences between housing systems. Therefore, it is possible to measure immunological changes at a cellular level, both *in vivo* and *in vitro*, in order to determine differential responses to stressors, between smaller numbers of animals. Among sows, McGlone et al (1993) found no differences in immune measures between those housed in stalls and those housed in tethers. However, Nicholson et al (1993) compared stall-housed sows with sows housed in groups of three, and found that stalled sows and subordinate group sows had higher Natural Killer cell activity than dominant group sows. Restraint of young pigs has been shown to reduce the size of the thymus gland and decrease the size of the PHA skin swelling (Mertshing & Kelley, 1983) as has weaning of piglets younger than five weeks of age (Blecha et al, 1983).

A great variety of stressors can lead to reduced immunity, but that this reduction may only become apparent if the individual is exposed to infection. Measures of cellular immunity can therefore highlight welfare problems which may not otherwise be apparent

2.6 Pathological indicators

Pathological changes are known to develop as a consequence of both long-term and short-term exposure to stress and can include renal and cardiovascular lesions, gastric ulceration, hypertension and changes in weight of certain organs. In the majority of cases, these pathological changes are associated with exhaustion of an animal's coping mechanisms, and as such, they are regarded as indicators of the maximal or final response to stress. However, Manser (1992) proposes that there is a possibility that pathological changes can occur before exhaustion of an animal's coping mechanisms and the presence and severity could give an indication of an individual's welfare within, for example, a housing system. The drawback is that pathological changes can only be fully investigated post-mortem and as such, will only be useful in helping to improve the welfare of similar individuals living in the same system, and not the individual itself. For a full review of pathological lesions related to stress, see Manser (1992), which reports mostly on work carried out on laboratory animals.

However, there have been some studies carried out on farm animals, and more specifically on pigs. Ratcliffe et al (1969) noted that pigs that were previously group-housed became "withdrawn" when subsequently housed singly and had a greater degree of arteriosclerosis than pigs which remained in groups. Arteriosclerosis is believed to be linked to persistent vasoconstriction as a result of sustained sympathetic nervous activity (Schneidermann, 1983). Severe restraint has been shown to cause myocardial necrosis in "normal" pigs (Wutzen et al, 1987), a condition which has also been demonstrated in pigs suffering from Porcine Stress Syndrome, when subjected to transport and handling (Johansson & Jönsson, 1977). Johansson et al (1982) proposed that this myocardial necrosis was due to stress-related catecholamine release.

Pigs subject to transport and handling stress are known to be prone to pathological changes in muscle biochemistry, which is apparent after slaughter. If pigs are mixed into groups prior to transport and lairage, there may be an upsurge in fighting which can lead to muscle glycogen depletion. This results in low lactic acid production and high muscle pH, giving rise to Dark Firm Dry (DFD) meat. Conversely, short term stress may result in rapid glycogen utilisation resulting in high concentrations of lactic acid and low pH in muscle, giving rise to Pale Soft Exudative (PSE) meat. The occurrence of either of these, indicates poor welfare prior to slaughter.

As stated earlier, a major problem within the breeding herd is that of lameness. It is the second commonest cause of culling of breeding sows, costing the industry anywhere between £3-8 million per year (Smith, W. pers comm). Lameness can be caused by: i) congenital defects, e.g. "splayleg", ii) infectious diseases, e.g. Mycoplasmal arthritis, "joint ill", iii) physical injury, most often due to floor and pen fittings, and including abrasions, bruising, damage to tendons, ligaments and muscle, and bone fractures, and iv) genetic diseases such as osteochondrosis. Confined housing conditions for sows are known to increase the incidence of lameness (Bäckström, 1973, de Koning, 1983, Tillon & Madec, 1984) but the exact causes, which could be useful pathological indicators of welfare, have not been described.

Bone strength has been used as a pathological welfare indicator, especially in comparisons of housing systems, but most work has been carried out on hens, where large numbers are easily obtainable for comparison. The housing system has been shown to affect bone strength, probably due to the amount of exercise that it permits. Meyer & Sunde (1974) increased bone breaking strength of caged layers by a few minutes on an exercise machine.

McLean et al (1986) found stronger tibiae in aviary layers than caged layers, and noted that aviary birds typically moved seven times as far during a specified time period. Knowles & Broom (1990) have also noted similar differences in bone strength between hens housed in different systems. Lanyon (1984) has proposed that with decreased dynamic loading, calcium is mobilised from the bone under hormonal control. The mechanism by which this occurs is not known (Lanyon, 1987).

Other possible factors that may influence bone strength include genetic strain (Rowland et al, 1972), diet and reproduction. In pigs, there have been numerous studies into the effects of differing levels of calcium and phosphorus in the diets on bone strength (e.g. Reinhart & Mahan, 1986, Combs et al, 1991, Hall et al, 1991), but none specifically into the effects of confinement on pig bone strength. Reproduction will also have an effect on bone strength, due to the high calcium demands placed on the female during fœtal growth, lactation and, in the case of poultry, egg-shell formation. Kornegay et al (1973) found that the breaking strength of sows' femurs decreased with parity number. This effect was also demonstrated by Nimmo (1980) using two sets of gilts, one set having undergone a single gestation and lactation, and the other remaining unserved.

Osteochondrosis has been shown to be widespread in growing pigs, and also in young breeding sows between the ages of 1-1½ years (Grøndalen, 1974). Incidence and severity of this condition is known to vary between breeds and is especially prevalent in fast-growing, long bodied breeds such as Landrace (Goedegebuure et al, 1980), where incidence may be as high as 100%. Rate of growth appears to be the most important factor, as demonstrated by the effect of PST (Simonsen, 1993). It is unknown what effect confinement whilst still growing has on the incidence of osteochondrosis.

Pigs do not readily show signs of discomfort, especially with leg problems, and whereas externally, welfare may appear good, internally the pathological reality may be very different.

CHAPTER 3

Overview and aims of the research

3.1 Background to the need for research into the effects of dry sow housing on welfare at farrowing.

Presently, the majority of sows in the EEC pig industry farrow in confinement, in commercial crates, regardless of the system in which they previously gestated. Within continental Europe, most sows are housed in confinement throughout gestation and lactation, and therefore do not undergo a large change in environment when they are moved to farrowing accommodation. However, in the UK, with legislation banning stalls and tethers nearing, most sows will be moving from an open environment during gestation into confinement at farrowing, and the effects of this transition are largely unknown. The majority of studies into sow welfare, as detailed in the literature review (Chapter 2) have tended to concentrate either on the dry sow environment or the farrowing environment, and little has been done to address any relationship between the two.

Where comparisons have been made, such as the study by Hansen & Vestergaard (1984) which compared tethered (T) and loose (L) housing systems for both gestation and farrowing (thus giving four treatments; TT, TL, LT, LL), a number of differences between treatments, both in terms of production and behaviour have been noted. Similar differences have been noted by Bäckström (1973) and Cronin & Simpson (in press), with the general conclusion that a change from one environment type during gestation to another during farrowing, together with the environment itself, can have a deleterious effect.

Currently, where open farrowing systems are in use, there seems to be a tendency towards modification of the system to allow confinement of the sow before, and up to about 48 hours after, parturition, in the belief that this minimises piglet deaths. After this, the restrictions are removed and the sow is allowed access to the whole pen. Research has already shown that it is around the time of parturition that the sow's maternal behaviour is most prominent, and to restrict her at this time appears more likely to have a detrimental, rather than beneficial, effect on the welfare of the sow and her litter.

Thus, two periods need to be focused upon; the first is the time of transition and adjustment to the farrowing accommodation, and the second is the time around parturition. A better understanding of these two periods is necessary for conclusions to be made about the farrowing sow's welfare with respect to the housing system used for gestation.

3.2 General aims

The general aims of the proposed research are to assess and compare the welfare of sows from confined and loose dry sow housing systems, during movement and adjustment to confined and loose farrowing systems, and to highlight and investigate areas which influence the welfare of the litter. These aims will be achieved by using measures of behaviour, physiology and pathology. Overall, it is hoped to show that welfare can be improved by moving towards less intensive husbandry systems, i.e. moving away from stalls and farrowing crates towards group housing and farrowing pens, without compromising production figures and economic viability. It is also hoped to indicate problematic welfare areas within these systems, that are in need of further study.

Together with the obvious aims of contributing further to the specified subject area, this thesis will also include a review of relevant research (Chapter 2) in the areas of the assessment of welfare of sows in dry sow systems and farrowing systems, and more generally, in the use of relevant welfare indicators. This review will be referred to in order to support the hypothesis that the type of dry sow system will affect the welfare of the sow and her litter at farrowing.

Another important general aim, is to investigate the applicability of certain parameters used in welfare assessment. Behavioural parameters have been fairly well tried and tested, but cannot stand alone as an indicator of the welfare of an individual. Information derived from behavioural studies needs to be supplemented by other measures such as physiology, endocrinology, immunology or pathology. In many cases, methods of data collection and/or interpretation are relatively new and problematical (Rushen, 1991), and are therefore in need of further validation. General methodology is described in detail, in Chapter 4.

3.3 Specific aims

3.3.1 The effects of dry sow and farrowing accommodation on production figures

As has been stated in Chapters 1 & 2, a study of production figures has two important functions. Firstly, it is a convenient "starting-point" from which to gain an initial indication of where welfare problems may occur. Secondly, production will be the first area that commercial producers will look at, before any recommended changes are likely to be implemented. In the majority of cases, differences in production figures only become apparent with a very large number of replicates, and may then be subject to confounding factors such as parity number or genetic stock. The study investigates herd records and discusses production results, for a total of about 500 gestations and farrowings, in 63 sows of similar age, parity and genetic stock. This allows a comparison of results purely in terms of the effects of housing.

The aims of this study are to compare herd production in terms of dry sow system only, farrowing system only and also in terms of the two combined, in order to highlight areas for further study. The results are discussed in Chapter 5.

3.3.2 The effects of dry sow housing conditions on behaviour and production at farrowing

It is known that sows exhibit certain behaviour patterns exclusively prior to farrowing and that this behaviour can be modified by type of farrowing accommodation. However, little is known about the effects that the housing system during the previous gestation has, on the behaviour of the sow around the time of farrowing and subsequent production. With the wide variation in dry sow housing systems currently in use within the UK pig industry, the importance of determining any effects becomes apparent, both in terms of welfare and economics.

The aims of this study are to compare the pre-farrowing behaviour and subsequent production of sows housed in four different treatments. The study is described in Chapter 6.

3.3.3 The effects of dry sow and farrowing accommodation on heart rate during specified behaviours

As a physiological indicator of welfare, heart rate monitoring has recently been undergoing rapid development as technology improves. It can be used to give an indication of cardiovascular fitness, and also an indication of the degree of sympathetic arousal in response to external and internal stimuli. Thus, it can be used to compare the cardiovascular fitness of confined and non-confined sows, and also give an indication of relative responsiveness to stimuli such as feeding and the suckling event.

The aims of this study are to compare the heart rate of sows housed in different dry sow systems when carrying out categorised behaviours. Comparisons are also made with sows lactating in farrowing crates. This study is described in Chapter 7.

3.3.4 The effects of dry sow housing conditions on bone strength and muscle conformation

Together with a possible effect on muscular fitness, lack of exercise has also been shown to effect bone strength (Meyer & Sunde, 1974). In commercial poultry production, this has important welfare considerations especially when it comes to handling of spent hens that were caged during the laying period. In some instances, up to 50% of hens have broken bones prior to stunning (Gregory & Wilkins, 1989). Again, it is likely that long-term confinement of sows will result in decreased bone strength, and also lead to an alteration of muscle conformation due to decreased locomotory exercise. This may have consequences on the incidence of severe lameness, and also affect the ease of lying and standing.

The specific aims of this study are to compare bone strength and individual locomotory muscle mass of sows housed in confined and non-confined systems. Relationships with times taken to lie down will be investigated. This study is described in Chapter 8.

3.3.5 The effects of dry sow and farrowing accommodation on lying and standing times

The ease with which sows stand up and lie down can have implications for both for the welfare of the sow in the dry sow environment, but also for the litter in the farrowing environment. Studies on cows housed in loose stalls or tied, have shown that the restriction afforded by tying, results in increased time taken to lie down (Herlin, 1991, Krohn & Munksgard, 1993). This is most probably because of decreased muscle fitness due to lack of locomotory exercise. In pigs, it is likely that those housed in stalls and tethers during gestation, will also suffer from a lack of muscular fitness, and thus encounter difficulty in lying and standing. In the farrowing environment, alteration of standing and lying behaviour may have consequences for piglet mortality due to crushing.

The aims of this study are to compare the time taken for sows to lie down in different dry sow environments, and to investigate any factors that may contribute to differences. Furthermore, the time taken to lie down will then be investigated in farrowing crates, together with any link to piglet mortality. The study is described in Chapter 9.

CHAPTER 4

General materials and methods

4.1 Introduction

This Chapter outlines the materials and methodology common to a number of the experiments described in the following chapters. It includes details of the animals and housing systems used in all the experiments, together with descriptions of the experimental materials and methodology used in studies of behaviour, heart rate and pathology.

4.2 Animals, housing and management

4.2.1 Introduction

The majority of the experiments were carried out at the Pig Unit belonging to the Cambridge University Veterinary School's Animal Welfare Group, except for part of the work on lying times, which was carried out on a commercial unit. The Pig Unit is run as a commercial enterprise, but management of the herd is somewhat flexible in order to accommodate research studies. This section describes the animals used in the experiments, the housing systems in which they are kept and the management regimes used.

4.2.2 Animals

The Animal Welfare Group's Pig Unit was originally set up for a long-term study on sow welfare in relation to housing systems, comparing three dry sow systems and two farrowing systems. The Unit was started in 1988 with 67 gilts supplied by Master-breeders UK Ltd (Tring, Hertfordshire), which were introduced into one of three different dry sow systems over a period of about six months. All gilts were Large White x Landrace and were from the same genetic stock and in some cases, the same litters. At the start of studies described in this thesis, in October 1990, the herd comprised of 63 sows, all ranging from fourth to sixth parity.

Unlike a commercial unit, there was no policy of ongoing herd replacement, so that for the total duration of these experiments, herd structure was stable, with all sows of similar age and parity number at any one time. Sows were always returned to the dry sow system to which they had originally been assigned, after farrowing and service. Management and husbandry regimes were kept constant throughout the experimental period.

4.2.3 Housing systems

The Unit encompasses three different dry sow systems and two farrowing systems. The dry sow systems are housed in three adjacent buildings of identical design externally, but each modified internally to accommodate one of the following systems:

i) Individual stalls (see Figures 4.1 & 4.2 and Plate 4.1). There are 12 stalls consisting of metal tubular frames (manufactured by Quality Equipment, Bury St. Edmunds, UK), bolted to a raised, partially slatted concrete floor. There is a continuous concrete feed trough running along the front of the stalls, with individual nipple drinkers for each sow. A simultaneous feeding system is also situated at the front of each stall above the trough. There is a removable barrier at the rear of each stall. The building also contains a single strawed pen for sows needing special attention. Eleven sows were housed in this system.

ii) Small group pens (see Figures 4.3 & 4.4 and Plate 4.2). There are three enclosures each holding 5 sows. Each enclosure consists of a strawed lying area, unstrawed dunging area and individual metal tubular feeding stalls (Quality Equipment) into which the sows can be fastened during feeding. There are two nipple drinkers per enclosure. A raised observation platform is situated in the middle of the whole building. There is also a single strawed pen. Fifteen sows were housed in this system.

iii) Large group house (see Figure 4.5 & 4.6 and Plate 4.3). The sows have access to nearly the whole building, which is divided into a strawed lying area and an unstrawed dunging area. A single electronic feeder station (Quality Equipment) with rear entry and front exit gates, is situated in a corner of the dunging area. There are five nipple drinkers and a water trough also sited in the dunging area. In the centre of the building, there is a wall 5 feet x 12 feet, to allow sows some protection from aggression. Above this is an observation platform. Thirty-seven sows were housed in this system.

As stated earlier, all sows only had experience of the one dry sow system to which they were assigned when the Unit was set up, and were returned after farrowing and serving elsewhere on the unit.

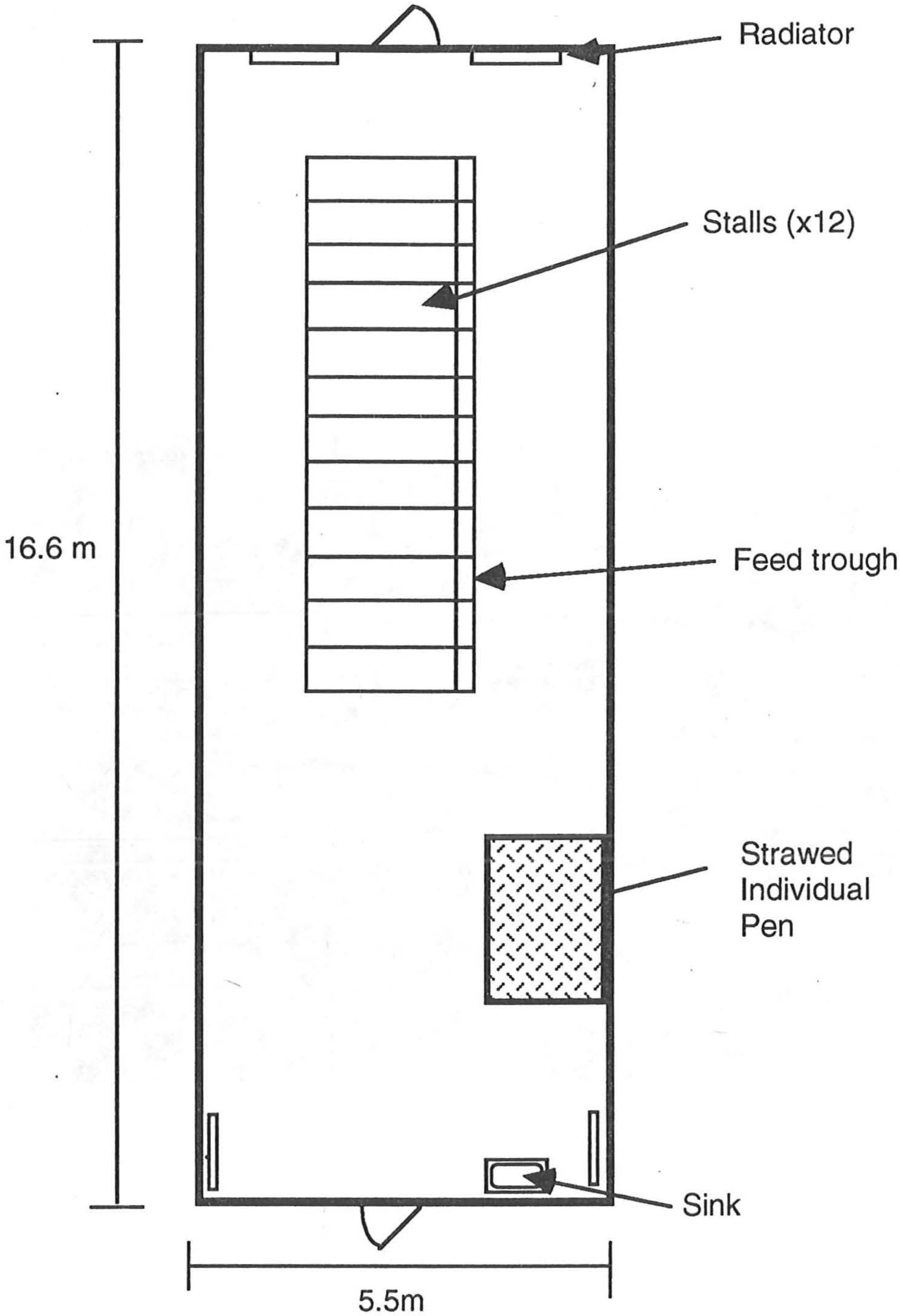
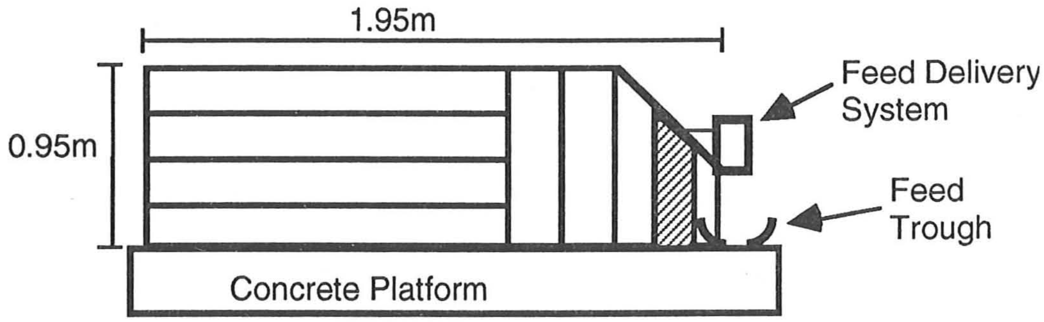


Figure 4.1 Plan of the Stall House.



Stall Width: 0.57m

Figure 4.2 Sideview of permanent stall

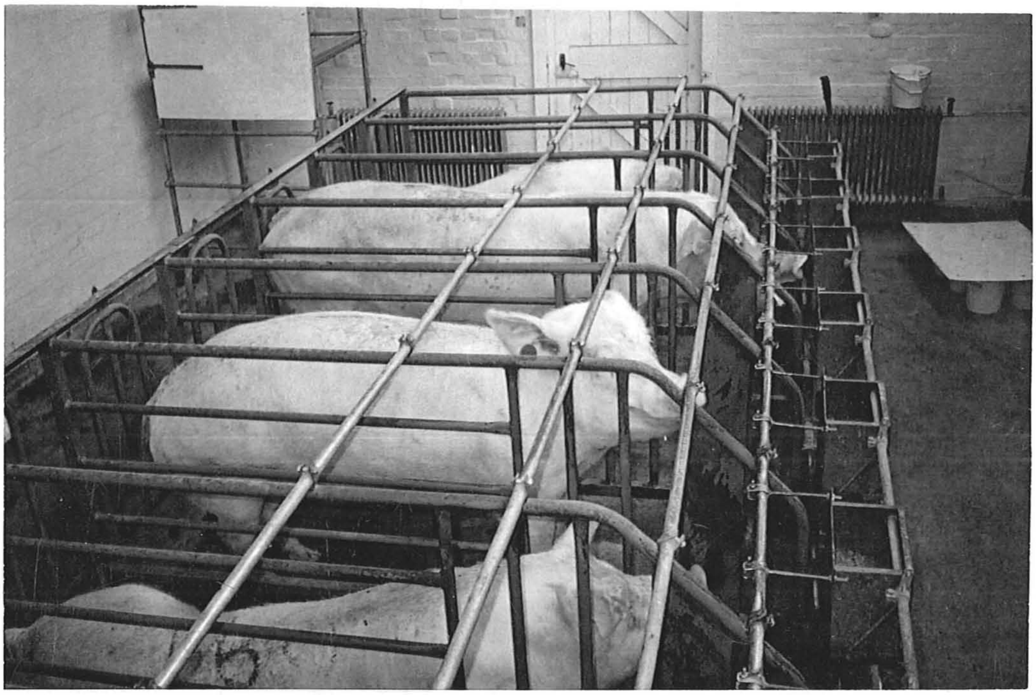


Plate 4.1 The Stall House

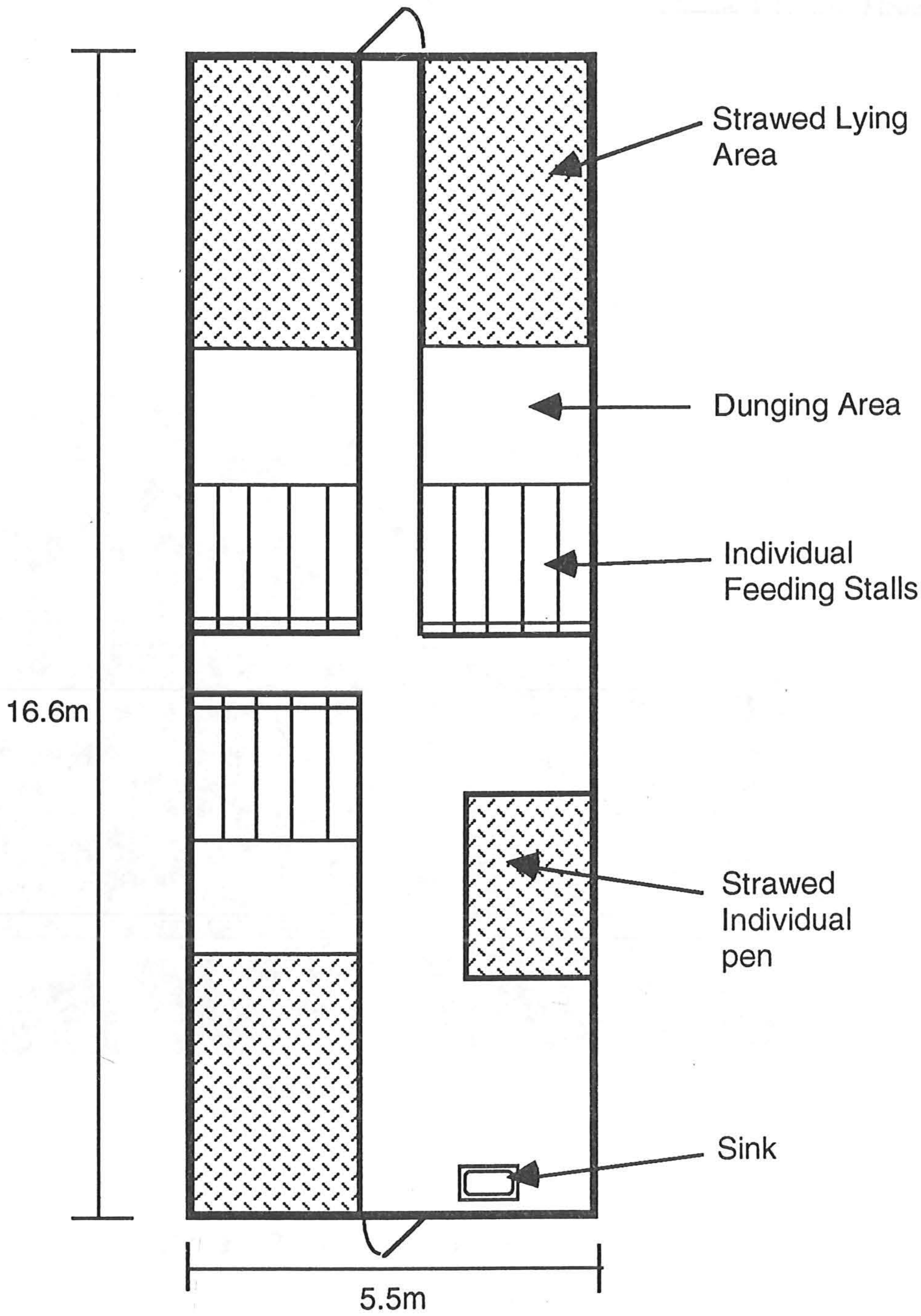
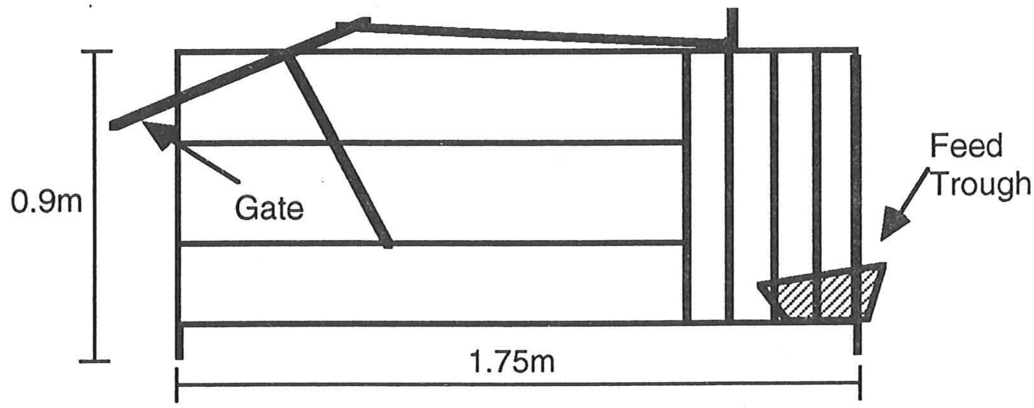


Figure 4.3 Plan of the Small Group House.



Stall Width: 0.41m

Figure 4.4 Sideview of individual feeding stall.

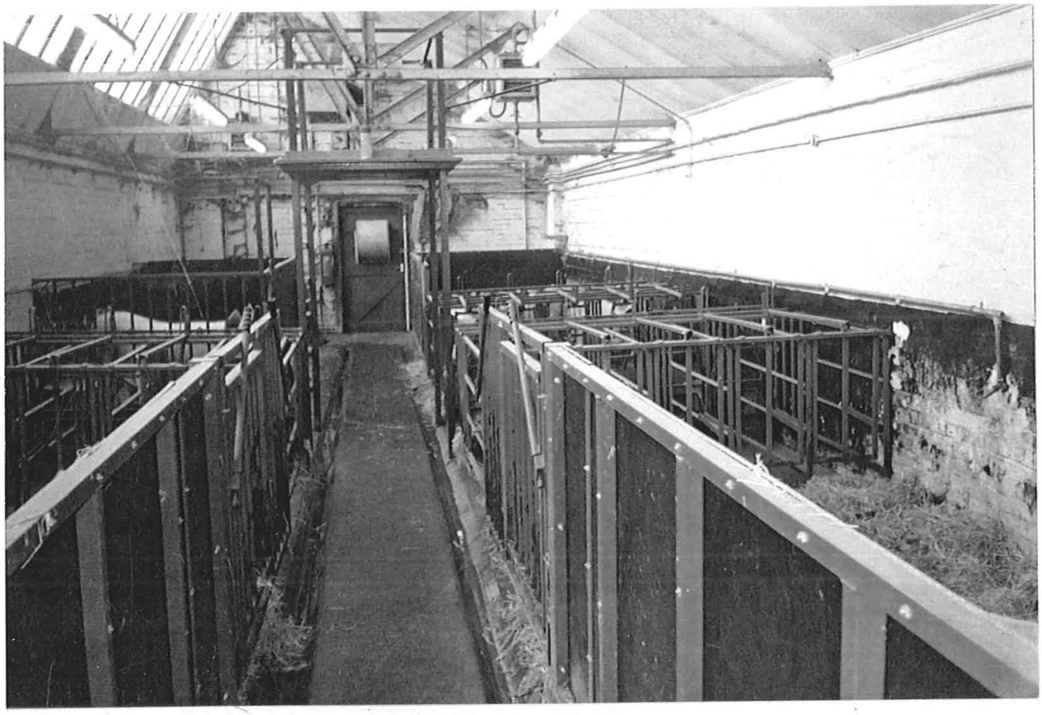


Plate 4.2 The Small Group House

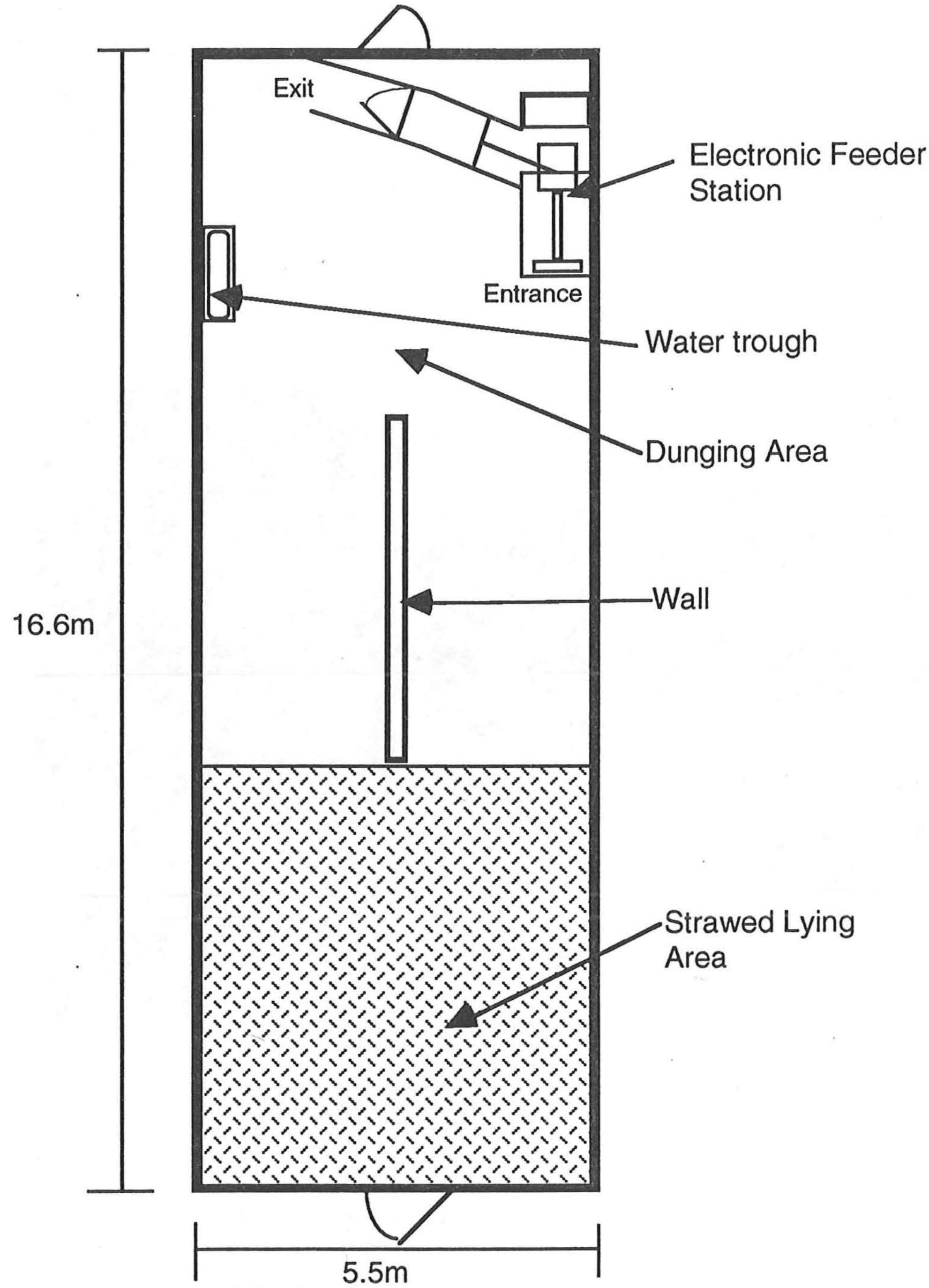
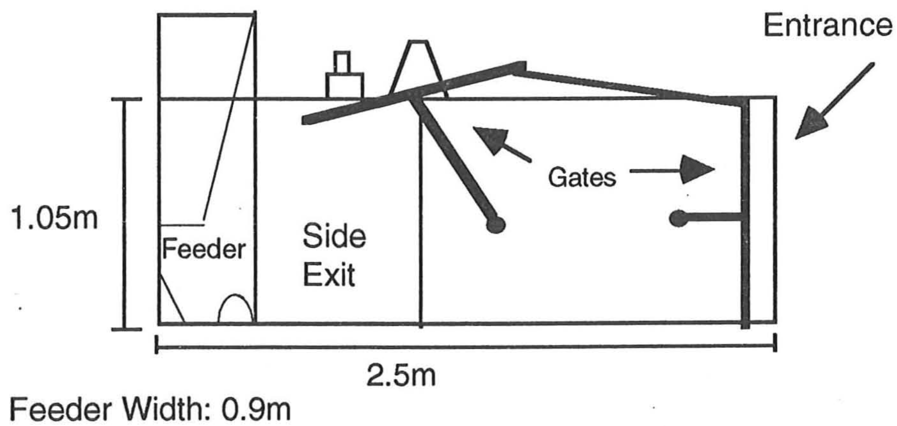


Figure 4.5 Plan of the Large Group House.



Feeder Width: 0.9m

Figure 4.6 Sideview of the Electronic Sow Feeder station

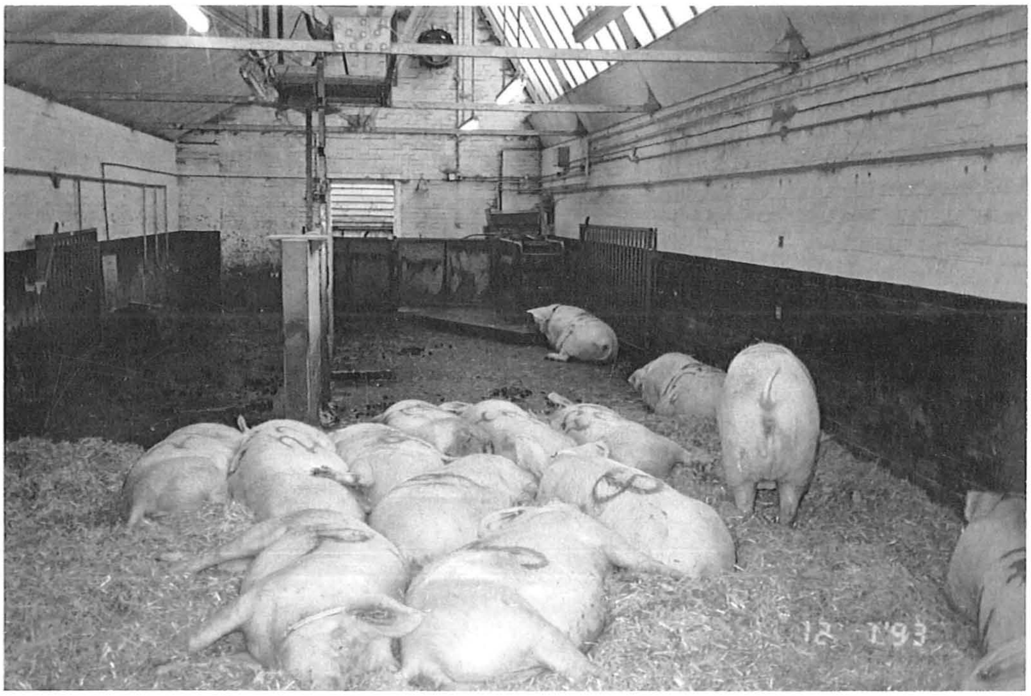


Plate 4.3 The Large Group House with Electronic Sow Feeder

The two farrowing systems are situated about 200 metres away from the dry sow systems in non-purpose-built buildings converted to accommodate one of the following systems:
i) Individual farrowing crates (see Figures 4.7 & 4.8 and Plate 4.4). Twelve commercial tubular metal farrowing crates (Quality Equipment), in 2m x 2.5m pens, are situated down one side of a converted poultry house. Each crate has a feed trough and nipple drinker at the front and removable access bars at the rear. There is a semi-enclosed piglet creep area with heating lamp in a front corner of the pen. The floor is solid concrete with a slight slope from front to back, to allow drainage. The bedding substrate is sawdust. There are ten weaner pens situated down the other side of the house.

ii) Individual farrowing pens (see Figures 4.9 & 4.10 and Plate 4.5). Six individual open pens are situated in a converted stables. Each pen consists of a strawed lying area and an unstrawed dunging area. There are farrowing rails running around three sides of the strawed area, 20 cm up from the floor and 20 cm out from the wall, to prevent the crushing of piglets when the sow lies down. A heated piglet creep area is situated in one corner of the strawed area.

The only other buildings in which sows may be housed, are the service pens and various isolation pens. The service pens comprise of a row of eight large kennel-type pens with covered lying area and an uncovered outdoor run, of which three are occupied by the herd boars. There are two designated isolation pens away from all other sow accommodation, to which ill or lame sows can be removed for treatment and recuperation.

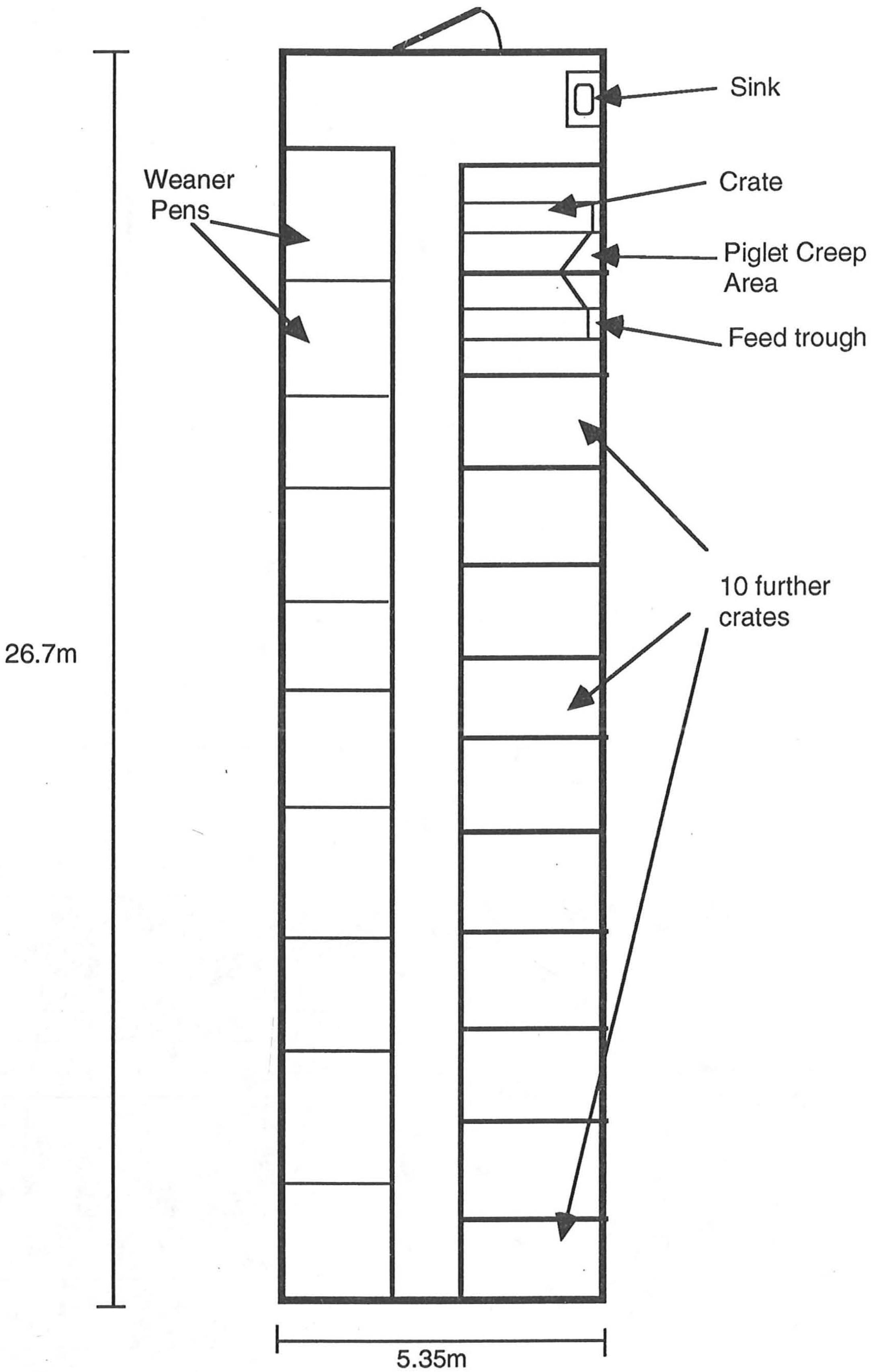


Figure 4.7 A plan of the Farrowing Crate House.

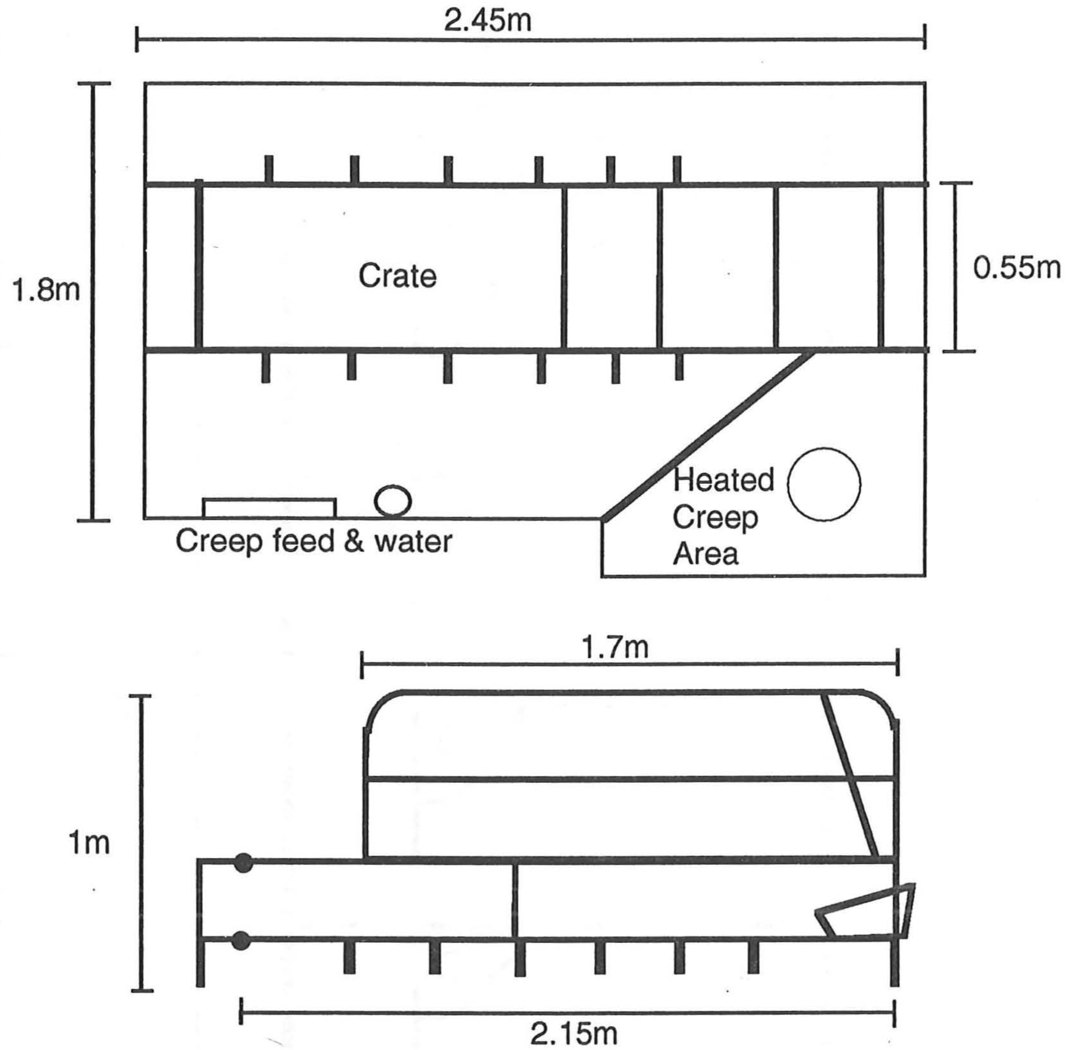


Figure 4.9 Plan and sideview of an individual farrowing crate.

Plate 4.4 An individual farrowing crate.

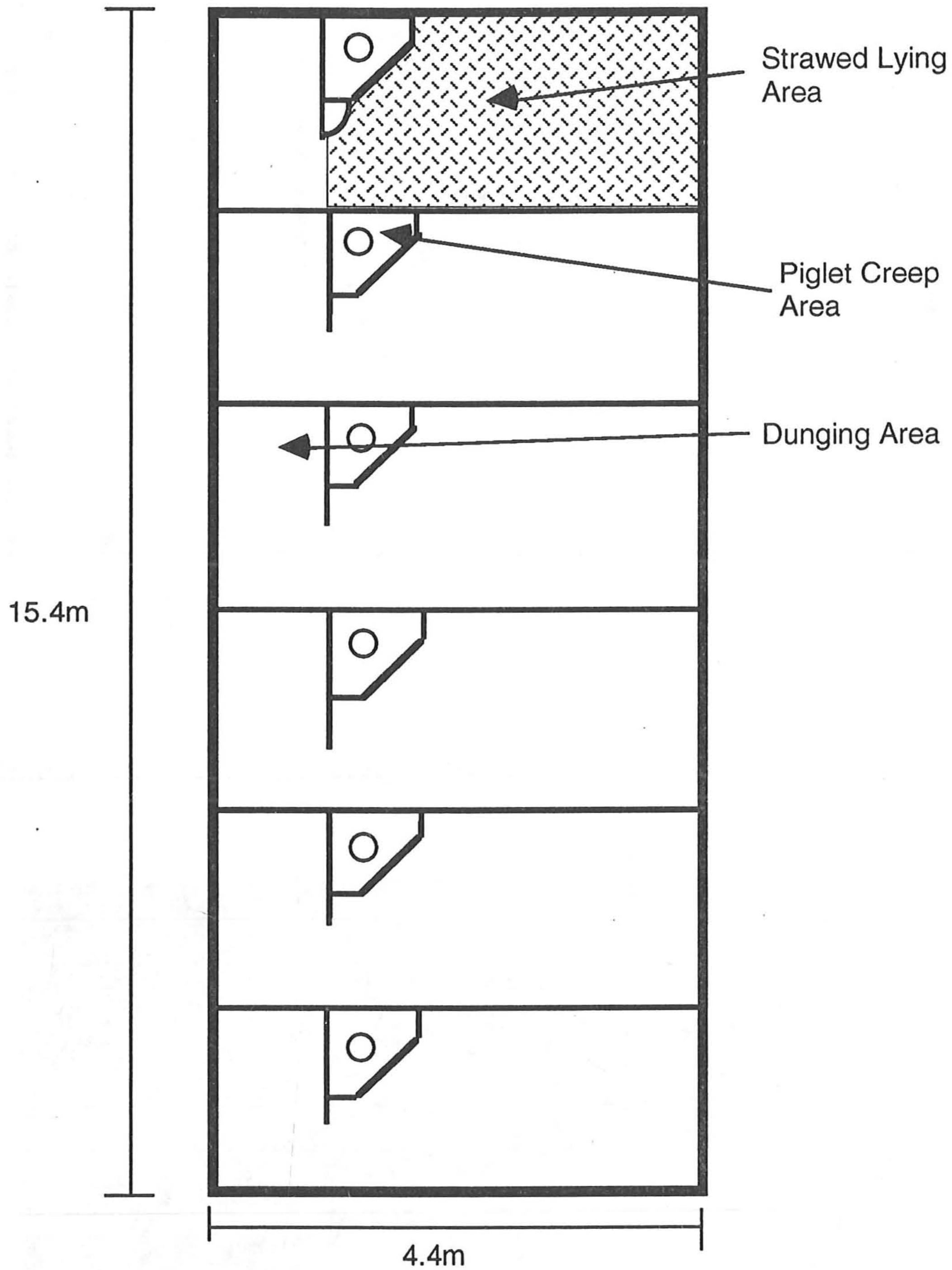


Figure 4.8 A plan of the Farrowing Pen House.

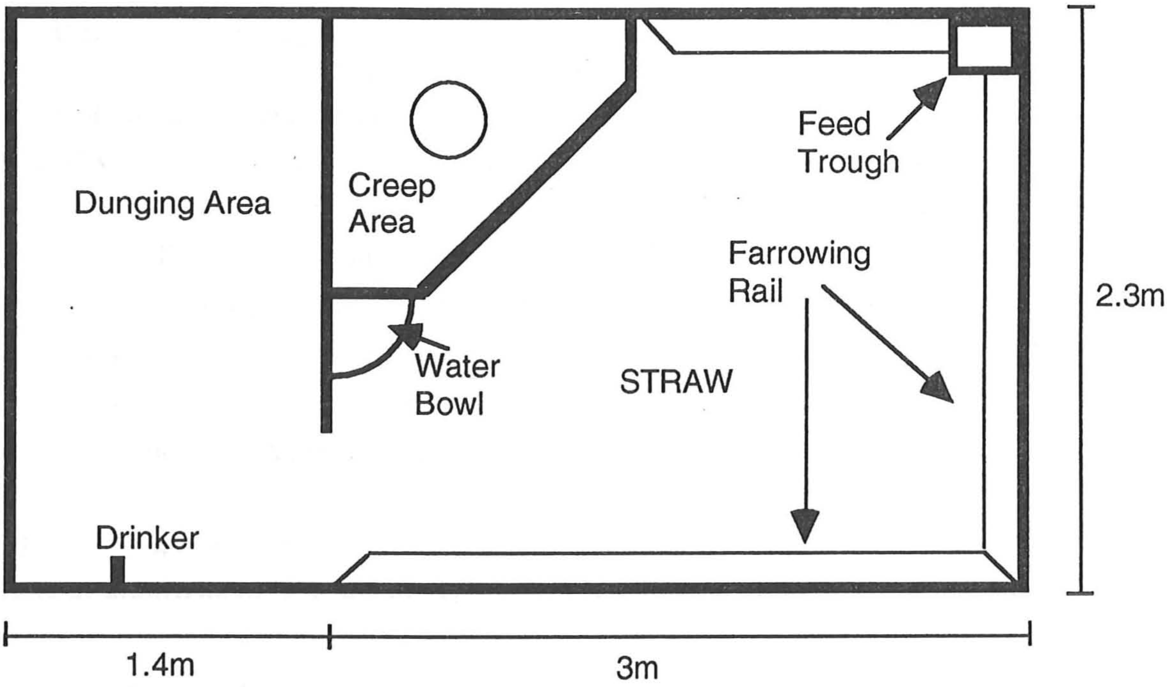


Figure 4.10 A plan of an individual farrowing pen.

Plate 4.5 An individual farrowing pen

4.2.4 Management regimes

The whole herd is managed by two staff who have total responsibility for the day-to-day husbandry of the stock. After weaning, the sows are removed to the service pens, where they are housed next to a boar to encourage œstrus. When signs of œstrus are detected, they are usually mated by one of three Large White boars, or occasionally, artificially inseminated. They are kept in the service pens for a further three weeks, to ensure that they have held to service, before being returned into their dry sow system. Where possible, the sows are not reintroduced into the group housing systems alone, but with two to four other sows with which they have been mixed a few days before.

In the dry sow environment, feeding occurs once a day. For the stalls and small groups, this is at approximately 7:30a.m. The stall sows are fed simultaneously, using a lever-operated feeding system which drops the ration into the feed trough. The sows in the small group are shut into the feeding stalls and then fed manually by a stockman. Whilst feeding occurs, the group pens and stalls are mucked out, and in the case of the pens, straw is added. Once this is completed, the group sows are released from the feeding stalls. The sows housed in the large group with the Electronic Sow Feeder (ESF) system, also invariably eat once a day, but the time of feeding is self-determined. On entry to the feeder, a computer reads the neck transponder worn by each sow, and delivers an amount of feed, pre-determined by the stockmen, in pulses of about 200g/min. The computer is time-controlled, with the feed cycle switching over 24 hourly, at approximately 3:00p.m. This system is also mucked out daily each morning, and straw added as necessary. The amount of feed each sow receives varies between about 2.5-4 kg and is dependent on stage of gestation and body condition.

The sows are housed in the dry sow system until about five days prior to predicted farrowing date , when they are moved to the farrowing accommodation. The choice of farrowing pen or crate will be entirely dependant on the state of current occupation. The farrowing houses are occupied using a cyclical regime, with sows at the same stage of gestation housed in adjacent crates. The next sows in, a few days later, will be housed in the next crates and so on up the house until it is full. The next sows will then be housed in the straw pens in the same way. Weaning will then also occur in the same order. This results in the crates and pens being "rested" for a period of time before introduction of the next pre-parturient sow.

Once in the farrowing house, feeding is carried out twice a day, once at about 8:00a.m. and again at about 3:00p.m. Each crate and pen is also mucked out at these times, and shavings (crates) and straw (pens) added as necessary. Feeding is carried out manually, and in the crates, is followed about 15 minutes later by manual delivery of a bucket of water. Again, the amount of feed given is dependant on the stage of lactation, and body condition. Weaning occurs on Thursdays, usually about 24 ± 3 days after parturition. The piglets are subjected to normal husbandry practices such as teeth-clipping and iron injections within the first 24-48 hours post-partum. After weaning, they are sold on for rearing.

It is very important that the day-to-day husbandry remains constant for the duration of any experiment, in order to reduce the number of confounding factors. This was especially important during the study on the effects of feeding on heart rate. During experiments that necessitated human input, this input was carried out by the usual stockman, and carried out during usual husbandry practices.

4.2.5 Other animals and housing conditions studied

As stated earlier, nearly all the studies were carried out on the Animal Welfare Group's Pig Unit. However, part of the study into lying and standing behaviour was carried out on a commercial unit owned by David Overton, Esq. near Mildenhall, Suffolk. The sows studied here were all housed in a single stall-house building, and were a mixture of Large White x Landrace and Large White/Landrace x Hampshire which enables outdoor rearing. There was some variation in age and parity number, and also some experience of different dry sow systems.

4.3 Behavioural studies

4.3.1 Introduction

The advantages of behaviour measurement as a welfare indicator have been discussed previously in Chapters 1 & 2. The methods by which behavioural data can be categorised, collected and analysed are numerous (e.g. see Martin & Bateson, 1986), and are usually designed or modified to suit a particular individual study. In the studies contained in this thesis, a number of different recording methods are described, which are outlined below.

4.3.2 Pre-farrowing behaviour

The most apparent indication of imminent parturition, is the massive upsurge in activity over the last 36-24 hours prior to the birth of the first piglet. For the study described in Chapter 6, this activity was categorised by the number of posture changes carried out during specified 24 hour periods. The use of this behaviour enabled comparison of sows farrowing in the crates and in the open pens, whereas measures such as locomotion or straw manipulation were only possible in the open system and would therefore be non-comparable.

On entry to the farrowing accommodation, five days prior to predicted parturition, the sows were video-recorded (time-lapse) continuously until parturition had occurred. The video data were then analysed to determine duration of and number of changes of four different postures. These postures were:

1) Standing - sow standing on all four limbs.
2) Sitting - sow "dog-sitting" on hindlimbs. This category also included incidences of kneeling.
3) Lying on Udder - sow lying in sternal recumbency, with no teats exposed.
4) Lying with Udder Exposed - sow lying in lateral recumbency, with all teats exposed.

4.3.3 Standing and lying behaviour

The physical acts of standing and lying can be particularly difficult for sows. This difficulty may be due to a combination of poor flooring, the effects of confinement and body shape, and may have consequences in terms of welfare, for both the sow and her litter. The movements carried out during lying and standing have been noted by Baxter & Schwaller (1983), in a study to determine the space requirements necessary for ease of movement. Lying was split into the following stages:

Lying

Stage 1 - One front foot is lifted and placed onto the floor so that the sow drops to a half-kneeling position. The second is then lifted, placed onto the floor, and the sow drops into a full kneel.

Stage 2 - The sow may pause before movement continues.

Stage 3 - The sow slides one knee forward along the floor and rotates the upper part of her body to bring a shoulder and side of head to rest onto the floor.

Stage 4 - Again, the sow may pause before movement continues.

Stage 5 - The sow lowers her hindquarters and rotates slightly causing the rear legs to slide sideways. The hindquarters then drop so that the upper thigh of one leg lands on the floor.

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Stage 5 - The sow lowers her hindquarters and rotates slightly causing the rear legs to slide sideways. The hindquarters then drop so that the upper thigh of one leg lands on the floor.

There is no gentle lowering of the hindquarters, but the force of the action may be reduced if the sow leans over against a solid object and slides herself down it. This can be observed in sows kept in any dry-sow or farrowing system. In a loose house, sows will use a wall or even another recumbent sow as an aid to lying. Those kept in stalls or crates use the sides of these as aids.

Standing was split into the following stages:

Standing

Stage 1 - The sow rises up onto her foreknees and pushes up with her forelimbs one after the other, rising to a sit.

Stage 2 - The sow may pause before continuing movement.

Stage 3 - The sow lifts her entire hindquarters off the floor, into a full standing position, in a single motion.

Unlike the lying behaviour, no use is made of any vertical surfaces.

In both cases, the total behaviour duration and also each individual stage duration was determined by hand-held stopwatch timings of real-time video-recordings and written onto a previously prepared sheet (see Figure 4.11).

Sow	Type	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Total (secs)
143	lie(open)	1.32	4.23	1.42	6.09	1.19	14.25
100	Std	2.41	43.93	1.02	-	-	47.36
162	lie(wall)	1.62	2.11	0.92	0.45	0.97	6.07

Figure 4.11 Example of prepared sheet for recording of standing and lying times.

4.3.4 Behaviours specified during heart rate studies

A number of different behaviours were categorised and recorded during the studies described in Chapter 7. One study was of heart rate of sows within the dry sow environment. For comparisons to be made, it was important to identify behaviours which were carried out in all three systems. After observation of sows in the systems, the behaviours that were identified as common were:

1) Lying with eyes closed (which was equated to basal heart rate) = Lie

2) Lying with eyes open = Lie

3) Feeding = Fdg

4) Drinking = Drk

5) Rooting = Root

Another study involved heart rate of sows, from different dry sow systems, within the farrowing crates. The same behaviour categories were used with the addition of suckling behaviour. For both these studies, behaviour was recorded by direct observation. The time displayed on the heart rate monitors and on the observer's watch were synchronised, so that when a specified behaviour was observed, the time, sow number and behaviour type were noted down, on a previously prepared checksheet (see Figure 4.12). The information contained on this could then be matched up to the heart rate trace after downloading.

Time started	Time ended	Sow Number	Behaviour
7.43.10	*7.46.23*	*143*	*Root*
7.44.35	*7.47.09*	*208*	*Drk*

Figure 4.12 Example of prepared checksheet used during study of relationship between heart rate and behaviour.

The final study involved heart rate during agonistic encounters. This was carried out on sows housed in the large group and measured heart rate during social encounters around the entrance of the ESF system. Again, behaviour recording was by direct observation, backed up by real-time video data. Agonistic encounters were divided into two types: Type 1 - involving no physical contact, Type 2 - involving physical contact. Behaviour was noted down on a previously prepared sheet (see Figure 4.13).

Time Started	Time Ended	Encounter Type	Winning Sow	Losing Sow
16.02.24	*16.02.39*	*type 1*	*35*	*133*
16.12.12	*16.12.22*	*type 2*	*100*	*162*

Figure 4.13 Example of prepared checksheet used during study of relationship between heart rate and agonistic interactions.

4.4 Heart rate monitoring

The heart rate monitors used in all the studies described in Chapter 7, were the Polar Sport Tester (Polar Electro Oy, Finland) consisting of an electrode belt, a clip-on transmitter and a wrist-watch receiver (see Figure 4.14)

The receiver collects and stores data from the transmitter and can average heart rate over either 5 second, 15 second or 60 second intervals. The interval setting gives memory capacity of 2hours 40minutes, 8hours 20minutes and 33hours 40minutes respectively. In all the studies, the interval was set at 5 seconds to give maximum detail. The electrode belt could fit around the thorax of the sow without the need for modification. Camcare ECG Gel (Cambmac Instruments Ltd, Cambridge, UK) was applied to the electrode surfaces and after ensuring that the skin surface was dry and clean, the electrode belt plus transmitter was placed around the thorax of the sow caudal to the forelimbs.

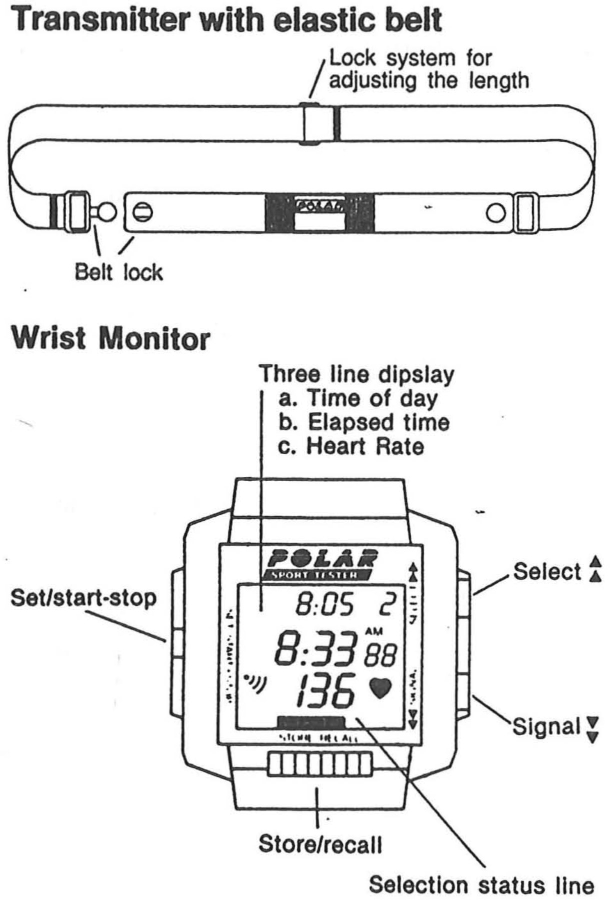


Figure 4.14 The heart rate monitor used in all heart rate studies

One electrode was positioned in the ventral midline with the other located on the left side of the thorax roughly in line with the olecranon process of the forelimb. The signal was then tested using the receiver, and if necessary, the belt was adjusted about 10cm up or down until the signal was consistent. The wrist-watch receiver was then fastened around the belt, positioned on the dorsal midline and switched on to start recording.

For smaller pigs and thin sows, the electrode belt did not maintain sufficient contact with the skin in the area of the electrodes. As an alternative, the transmitter was attached via two Red-Dot® (3M) stick-on electrodes. For this method, the areas of attachment were first shaved of any hair and washed with alcohol, to ensure good contact.

After the completion of data collection, the receiver was switched off and downloaded by "wire-free" contact via a Polar Interface (Polar Electro Oy, Finland) onto an Apple Macintosh P.C. and the data displayed in graphical and numerical form using Polar Heart Rate Analysis Software (Version 3.00). The numerical data were then analysed further, to enable statistical comparisons between treatments.

4.5 Bone strength and muscle conformation

4.5.1 Introduction

Confined housing systems restrict the amount of exercise that animals can perform, and in poultry, this has resulted in decreased bone strength. However, this effect of confinement has not been documented in other species, and nor have any effects of confinement on muscular conformation been investigated. Any differences in these parameters between sow housing systems may go some way to explaining the higher incidence of lameness encountered by sows housed in stalls and tethers.

4.5.2 Bone studies

Bone breaking strength *in vitro* can give an indication of how the bone will behave *in vivo*, when responding to mechanical over-loading. However, it can only give an indication and not a definitive measure, as the forces that act on the bones *in vivo* cannot be accurately reproduced. Also, for comparisons to be made between systems, and also between individuals, it was imperative that all bones underwent the same preparatory treatment and that breaking was carried out in a standardised way.

After slaughter, the left humerus and femur were carefully dissected out with muscle still attached. They were then placed in air-tight plastic bags, to minimise drying out, and stored overnight at 4°C. Storage at lower temperatures (e.g.-20°C) has been shown in some instances to alter the physical properties of the bone, and reduce breaking strength (Merkley & Wabeck, 1975). The following morning, as much of the remaining muscle as possible was cleaned off the bones. The importance of standard treatment for all specimens cannot be overstated. Removal of the muscle and connective tissue had to be carried out as carefully as possible without cutting the surface of the bone. The amount of tissue removal had to be consistent across samples, as presence of flesh has been shown to increase the amount of energy required to break bones (Currey, 1968). The bones were then measured to determine overall length and shaft diameter. A pen mark was placed at the shaft mid-point which was the point at which the breaking pressure would be applied. They were then placed back into air-tight bags and transported to the Cavendish Physics Laboratory for breaking.

Breaking was carried out using an Instron Universal Tester tensiometer (see Plate 4.6), set up for a three point bend test. The merits of this type of test as opposed to various shear tests and a four point bend test have been discussed by Knowles (1990), but it was generally thought that the three point bend test would present the least variable results and a quick and efficient method. The exact positioning of the bones upon a specially constructed two-point support, was of utmost importance. As stated earlier, the shaft midpoint was marked using a pen. The bones were placed across the supports so that the blunt semi-circular knife edge, which moved down centrally between them, applied pressure directly onto this marked point (see Figure 4.15).

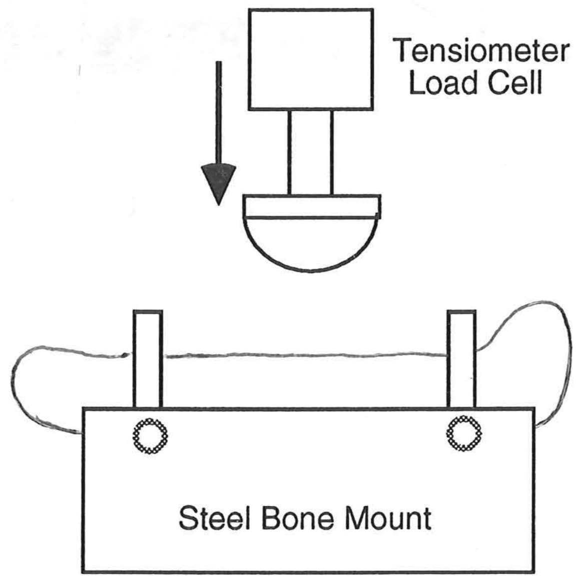


Figure 4.15 Diagrammatic representation of the Instron Universal Tester.

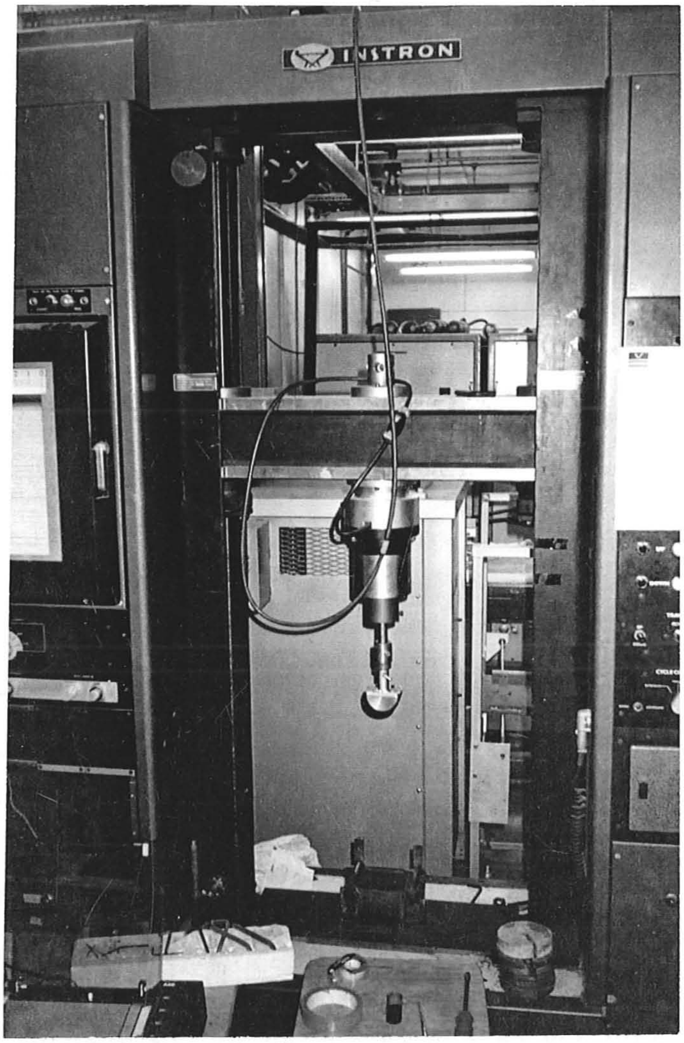


Plate 4.6 The Instron Universal Tester, showing the bone mount and the tensiometer load cell.

The rate of loading was kept at a constant velocity of 5 mm/minute, as variation in strain rate, has been shown to affect the final breaking strength (Wright & Hayes, 1976, Knowles, 1990). This it was hoped would minimise the variation due to biological differences in the size and shape of the bones. The support and blunt knife surfaces were covered with neoprene to ensure even distribution of the load and to minimise point stresses. The load cell output was then displayed on a chart recorder as a voltage, which had been previously calibrated using a standard weights, and breaking strength was taken as the peak load achieved before fracture (see Figure 4.16).

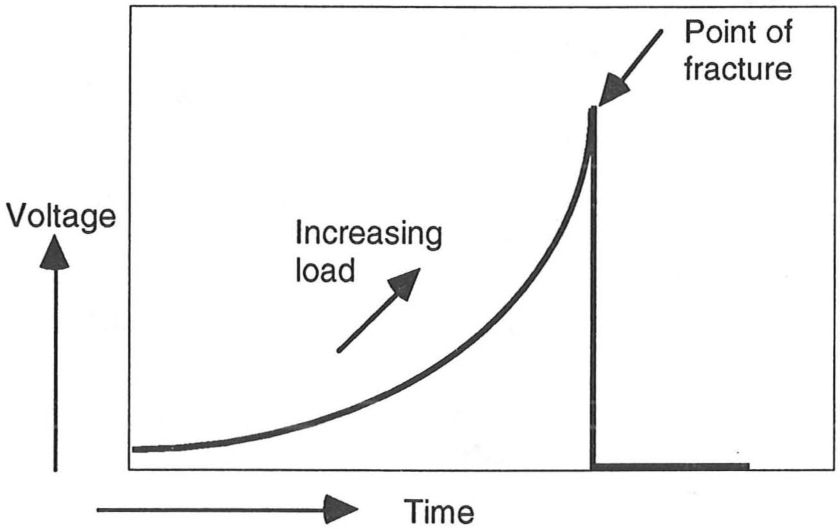


Figure 4.16 Diagrammatic representation of load cell output on chart recorder.

4.5.3 Muscle studies

Exercise of a specific muscle is essential to maintain its mass. Where exercise ceases, as in the case of plaster cast of a fracture, muscular atrophy can be readily seen. Therefore, it is likely that the mass of specific locomotory muscles will differ between sows kept in confined systems and sows kept in loose systems.

The muscles to be measured were chosen with reference to work by Tokuriki (1973a, 1973b, 1974) carried out on quadrupedal locomotion in the dog. In his studies, 50 individual locomotory muscles had electrodes implanted, and the dog was filmed during walking, trotting and galloping. From the combination of electromyographic and cinematographic data, he was able to analyse joint angles and muscle activity and thus determine individual muscular roles during locomotion. (For examples of graphical interpretation of muscle activity, see Figure 4.17).

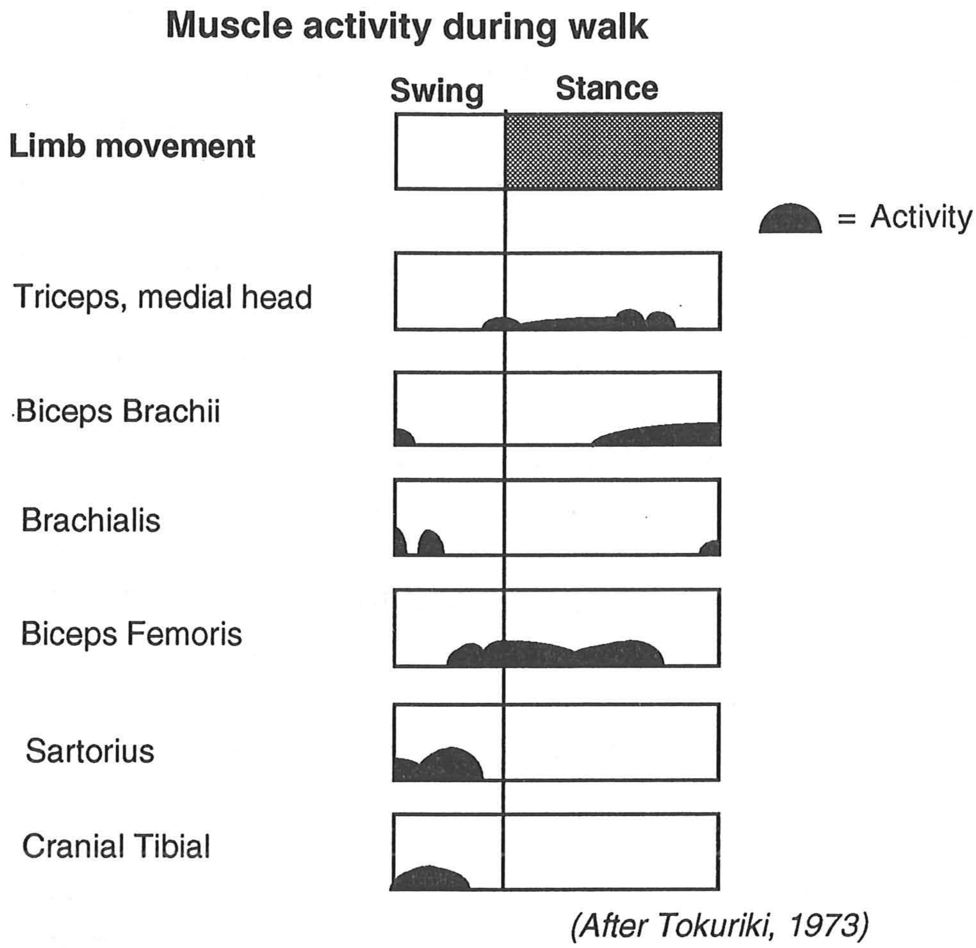


Figure 4.17 Graphical representation of muscle activity during walk.

However, there was no such information available for individual muscular roles during standing and lying movements, so relative importance of specific muscles during these activities were unknown. The other factors which determined the muscles to be measured were those of ease of identification, and length of time needed for removal. After consideration, five forelimb and nine hindlimb muscles were chosen as likely indicators of differences in muscular conformation caused by lack of exercise. These were:

1) **Forelimb**: Deltoid, Biceps Brachii, Triceps Brachii, Extensor Carpi Radialis, Brachialis.

2) **Hindlimb**: Superficial Gluteal, Tensor Fascia Latae, Biceps Femoris, Semitendinosis, Gracilis, Sartorius, Cranial (or Anterior) Tibial, Fibularis Tertius and Soleus & Gastrocnemius combined

After weighing and slaughter, the skin was dissected away from the carcass over the left forelimb and left hindlimb. Fascia and subcutaneous fat were also cleaned away, to reveal the superficial locomotory muscles. By using blunt and scalpel dissection techniques, the muscles were isolated and removed, taking care not to damage the underlying bones.

For muscles with tendinous attachments, the muscle belly was separated from the tendon for weighing. Each specified muscle was weighed individually to the nearest gram, using an electronic scales, to give the absolute muscle weight. This was then divided by the total body weight (in kilograms) to give the proportional muscle weight.

4.6 Statistical methods

All the statistical analysis was carried out on an Apple Macintosh personal computer, using the StatView™ SE+*Graphics* software package (Version 1.04, Abacus Concepts Inc., Berkeley, Ca., USA). Statistical tests carried out include; Student's t-test, one-way Analysis of Variance, two-way Analysis of Variance, Wilcoxon signed-ranks test, Pearson correlation, linear regression analysis and multiple regression analysis. For a detailed explanation of the criteria needed for the various statistical methods employed, refer to Sokal & Rohlf (1981).

a) Student's two-sample t-test - used to test for differences between two independent sample groups.

b) One-way Analysis of Variance - used to test for differences in the mean value between three or more independent sample groups.

c) Two-way Analysis of Variance - used to examine data according to two factors. It is assumed that each observation is composed of effects due to two factors. The analysis aims to detect whether the variations in the levels of the two factors do exert any significant effect on the observations.

d) Wilcoxon signed-ranks test - used to examine differences between paired variables.

e) Pearson correlation - used to determine the level of association between two variables.

f) Linear regression - used to estimate the best fitting equation between two variables.

g) Multiple regression - used when there are two or more independent variables linked with a dependent variable. Multiple regression can determine which independent variables affect the dependent variable significantly.

CHAPTER 5

The effects of six housing treatments on the productivity of sows over eight parities

5.1 Introduction

Analysis of production figures can often give an initial indication of areas in which there are welfare problems. The aim of this study was to examine thoroughly, the sow productivity records of the Animal Welfare Group's Pig Unit, over eight parities, and to carry out comparisons on the bases of housing conditions. The Pig Unit was initially set up for a long term comparative study of three different dry sow housing systems as described in Chapter 4. Combining these three systems with the two different farrowing systems, effectively allows comparison of six different housing treatments, namely:

Treatment 1	**Stall**-housed Sows farrowing in **Pens - (Stl/P)**
Treatment 2	**Stall**-housed Sows farrowing in **Crates - (Stl/C)**
Treatment 3	Small **Group**-housed Sows farrowing in **Pens - (SGrp/P)**
Treatment 4	Small **Group**-housed Sows farrowing in **Crates - (SGrp/C)**
Treatment 5	Large **Group** with ESF Sows farrowing in **Pens - (LGrp/P)**
Treatment 6	Large **Group** with ESF Sows farrowing in **Crates - (LGrp/C)**

All sows on the unit were the same age, and there had been no policy of replacement on the basis of litter size, high piglet mortality or infertility. Thus, comparison of production figures was carried out to give some indication of the effects that each treatment had on the welfare of both sows and piglets, without much of the modification that commercial, stock-management practises would impose. As stated earlier, however, whole-herd production figures can be misleading, and should be treated with caution, because the welfare of individual animals may be poor.

5.2 Methods

Sow productivity was recorded by the Unit manager, and noted down on prepared recording sheets. These included all other information necessary to expedite the day-to-day running of the Unit (see Figure 5.1). The sheets were updated weekly, using information written down daily in the stockmen's handbooks.

First Half.

Sow	Parity	Housing Type	Date Served	Sire		Possible Return Dates		Farrow Type + Sow Wt	Date Moved	Date Due	Date Farrow	Total Litter Birth Wt.	Nº of pigs born		
				Boar	AI	21d	42d						Alive	Dead	Mum

Second Half

Number of piglets			Date of Iron Injection	Date Due for Weaning	Date Weaned + Sow Wt.	Nº of Piglets Weaned	Total Litter Wean Wt.	Medication	Remarks
Fostered Out	Received In	Died							

Figure 5.1 Example of the prepared herd recording sheet.

For this study, the complete herd records were scrutinised and all relevant information extracted and compared. Comparisons, up to and including the eighth parity, were made on a number of parameters such as:

1) - Litter Composition: Number Born Alive
Number Born Dead
Number Born Mummified

2) - Total Live Litter Weight

3) - Average Live Piglet Weight

4) - Percentage Piglet Mortality (Parturition to Weaning) and Number Weaned

5) - Total Sow Weight-Loss (Pre-Partum to Post-Weaning)
& Sow Weight-Loss as Percentage of Pre-Partum Weight

6) - Weaning to Conception Interval

7) - Number of Returns to Service and Aborted Pregnancies

The comparisons were carried out on a number of bases. Initially, comparison was carried out by parity number, followed by comparison using dry sow housing system, comparison using farrowing system and finally using a combination of both to give the six treatments named above. Statistical methods used included Students t-test, Analysis of Variance (ANOVA) and Pearson Correlation. For ease of interpretation, the results will be presented in five sections: i) whole herd, ii) by parity, iii) by dry sow system, iv) by farrowing treatment, and v) by six treatments, with a preliminary discussion after each. The chapter will then be completed by a full discussion.

5.3 Whole herd figures (All Parities, 504 farrowings)

5.3.1 Results

For comparison, and where available, MLC recorded herd average figures for 1992 are in brackets.

1) Average Litter Composition

N° Born Alive = **10.876** ± 3.082 **(10.76)**

N° Born Dead = **0.755** ± 1.192 **(0.83)**

N° Born Mummified = **0.104** ± 0.443 **(0.11)**

2) Average Total Live Litter Weight

Average Total Weight (Kilograms) = **15.535** Kg ± 4.08

3) Average Live Piglet Weight

Average Weight (Kilograms) = **1.475** Kg ± 0.27

4) Average Percentage Piglet Mortality (Parturition to Weaning)

Average % Mortality = **12.486** % ± 14.105 **(11.7 %)**

Average N° of Piglets Weaned = **9.52** **(9.50)**

Piglets reared/Sow/Year = **22.65** **(21.47)**

5) Average Sow Weight Loss (Pre-Partum to Post Weaning)

Average Real Weight Loss (Kilograms) = **26.022** Kg ± 14.325

Average Weight Loss as % of Pre-Partum Weight = **11.427** % ± 6.68

6) Weaning to Conception Interval

Average Interval = **17.58** ± 3.056 days	(**21.49** days)
Average Weaning Age = **21.59** days	(**25.00** days)
N° of Litters/Sow/Year = **2.38**	(**2.26**)
Non-productive days/Sow/Year = **41.84** days	(**48.56** days)

7) Number of Returns to Service and Aborted Pregnancies

Successful services = **84.00** % (**86.30%**)

N° of Returns = **90**

N° of Aborted Pregnancies = **6**

5.3.2 Discussion

In all areas, the whole herd records compare favourably with the MLC average. Litter composition is similar, with the Unit herd having slightly more born alive and slightly fewer born dead. However, balancing this is a slightly higher piglet mortality rate, resulting in the number of piglets weaned per litter being essentially the same (9.52 vs. 9.50). One area where the Unit does have an advantage is with the number of piglets reared per sow per year, as a consequence of weaning age, and weaning-conception interval. Whereas on the majority of commercial units, the weaning age has risen back up from 21 days to an average of 25 days, on the University Unit, weaning has stayed around 21 days. This, combined with a better than average weaning-conception interval, has resulted in a greater number of litters per sow per year.

The Unit figures are roughly what would be expected, given the herd structure and the sow:stockman ratio. With two stockmen to 63 sows, labour costs would be prohibitively high for a commercial unit. However, the design of the buildings and the variety of accommodation types result in a workload which is too high for a single stockman to carry out. Thus, employment of two full-time staff effectively makes more time available to concentrate on the quality of stockmanship. The beneficial effects of this can be seen by the lower weaning to conception interval, where œstrous behaviour is unlikely to be missed. Also, piglet mortality can be deemed to be fairly low, considering a third of farrowings took place in open pens.

The Unit is disadvantaged by not having a herd replacement policy, so the records include those sows with fertility problems, which would ordinarily be culled out of a commercial herd. The results of this can be seen in terms of percentage of successful services, which is lower than the MLC average. This difference is probably wholly due to a handful of sows which persistently returned to service (e.g. Sow 109 - 8 returns, Sow 100 - 5 returns), and not as a result of husbandry practices.

5.4 Whole herd figures by parity

In this section, the production results of 63 sows over each of 8 farrowings are compared by parity number. No distinction is made in terms of dry sow system or farrowing system. Statistical analysis was carried out using Analysis of Variance (ANOVA) on a Statview SE+Graphics software package.

5.4.1 Results

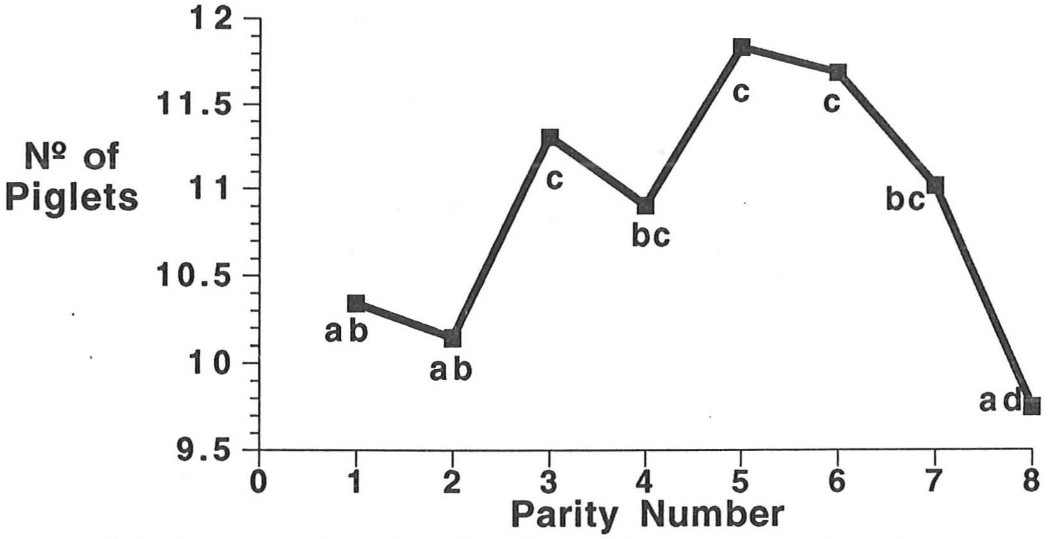


Figure 5.2 Mean number of piglets born alive per litter, for all sows over eight parities. a,b,c,d Points without a common letter are significantly different at $p<0.05$.

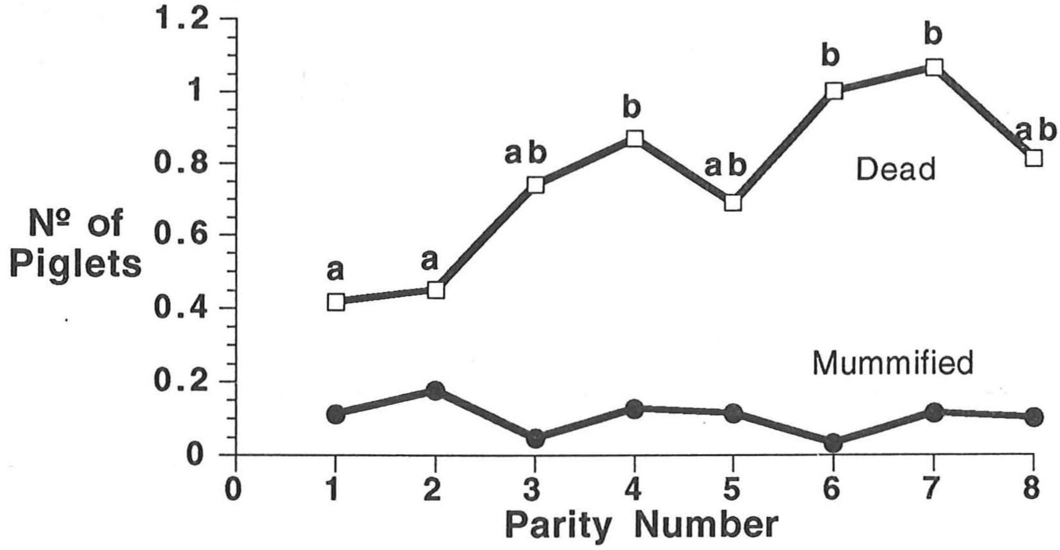


Figure 5.3 Mean number of piglets born dead and mummified per litter, for all sows over eight parities. a,b Points without a common letter are significantly different at $p<0.05$.

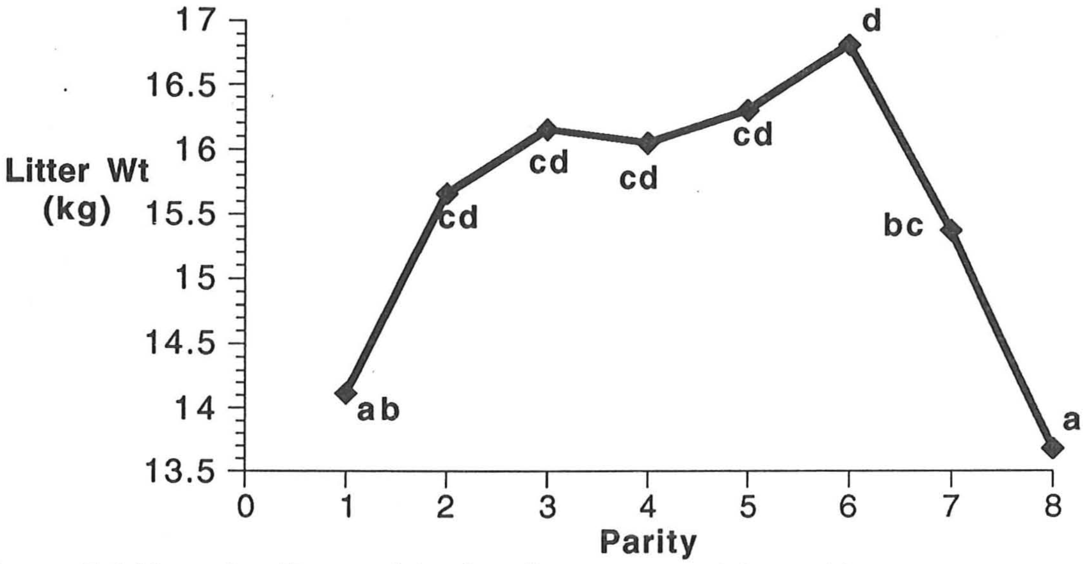


Figure 5.4 Mean live litter weight, for all sows over eight parities.
a,b,c,d Points without a common letter are significantly different at $p<0.05$.

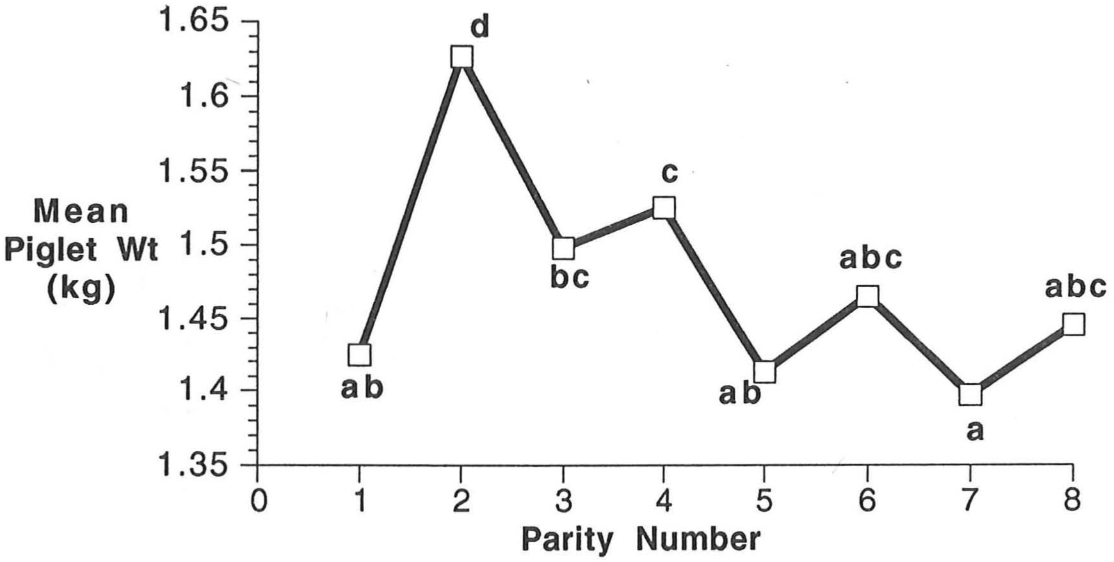


Figure 5.5 Mean live piglet birthweight, for all sows over eight parities.
a,b,c,d Points without a common letter are significantly different at $p<0.05$.

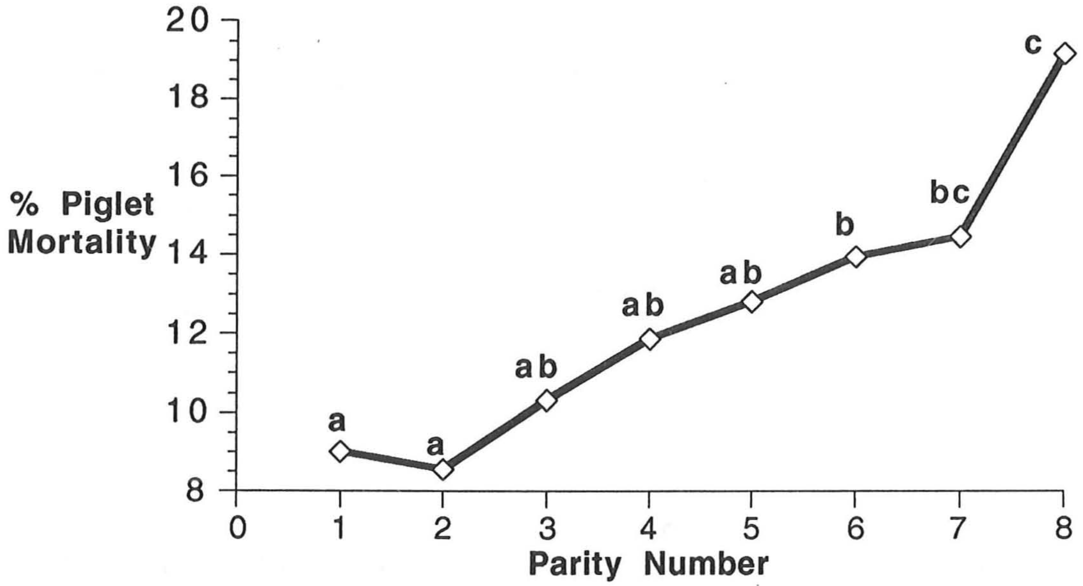


Figure 5.6 Mean percentage piglet mortality (birth to weaning), for all sows over eight parities. a,b,c Points without a common letter are significantly different at $p<0.05$.

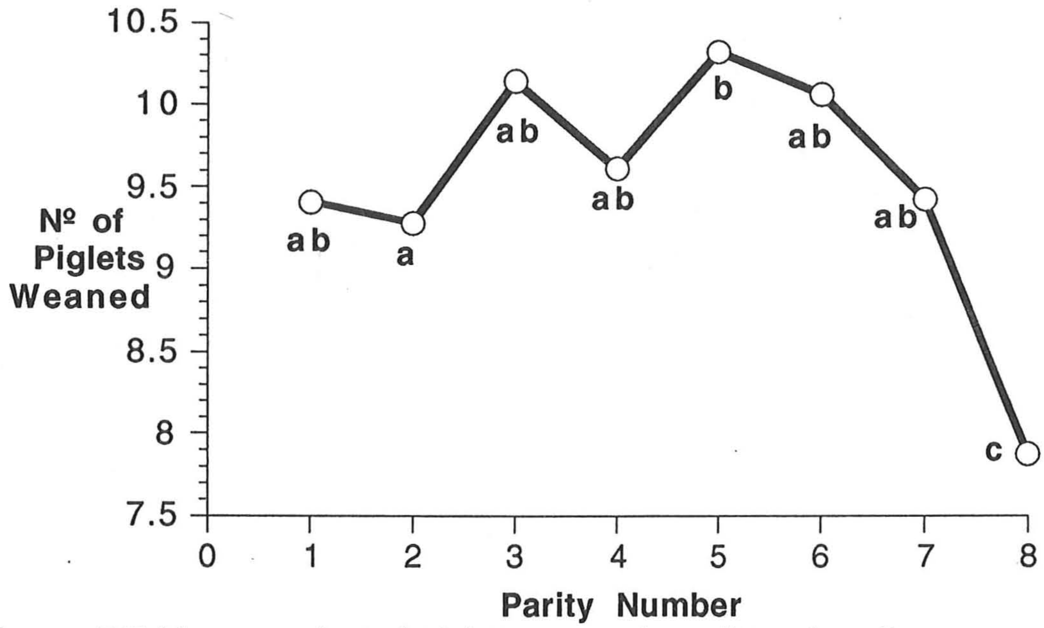


Figure 5.7 Mean number of piglets weaned per litter, for all sows over eight parities. a,b,c,d Points without a common letter are significantly different at $p<0.05$.

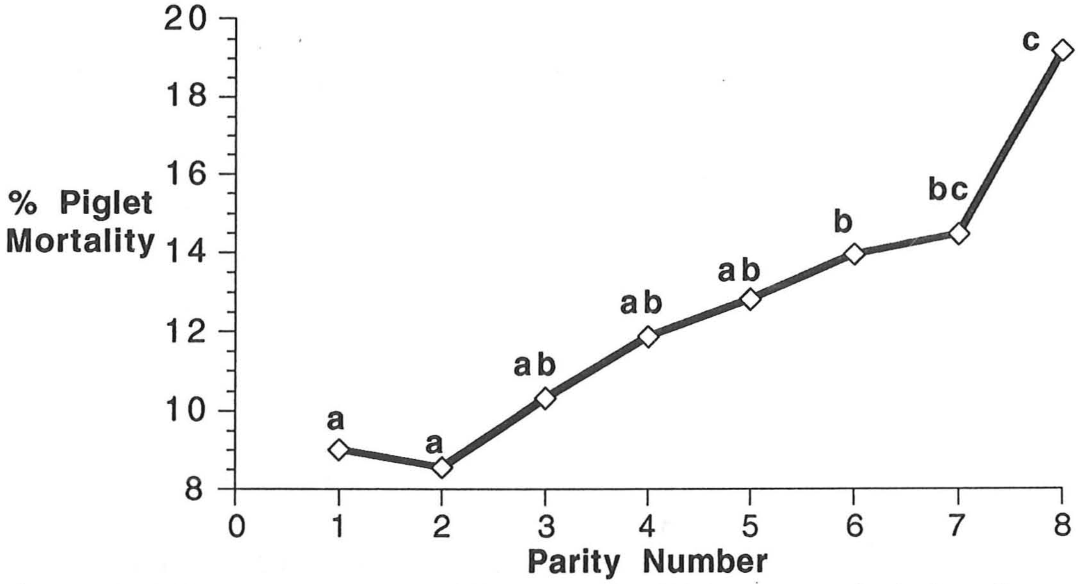


Figure 5.6 Mean percentage piglet mortality (birth to weaning), for all sows over eight parities. a,b,c Points without a common letter are significantly different at p<0.05.

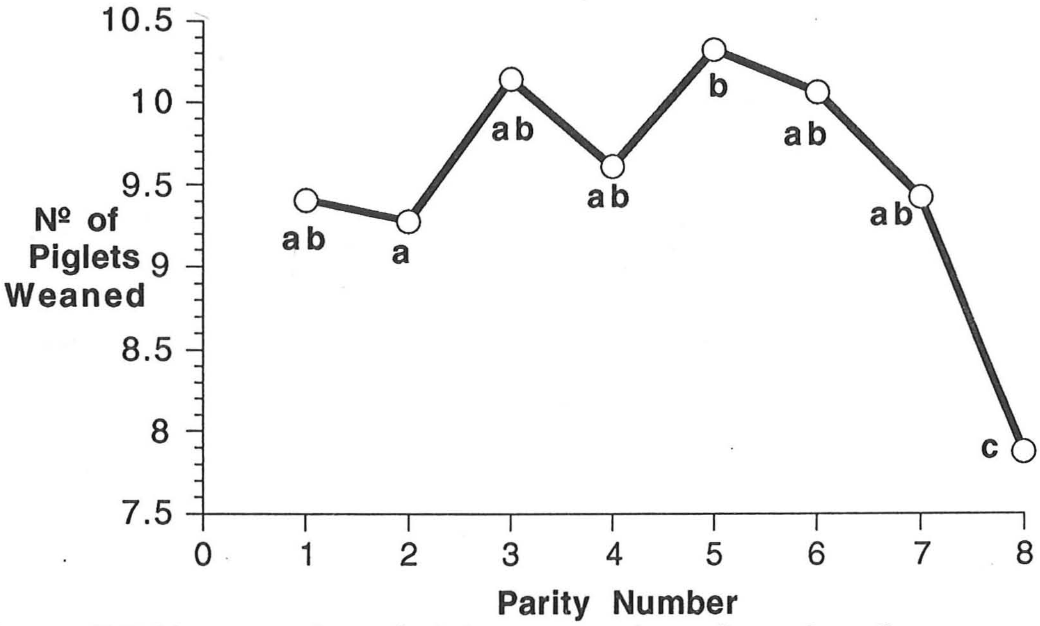


Figure 5.7 Mean number of piglets weaned per litter, for all sows over eight parities. a,b,c,d Points without a common letter are significantly different at p<0.05.

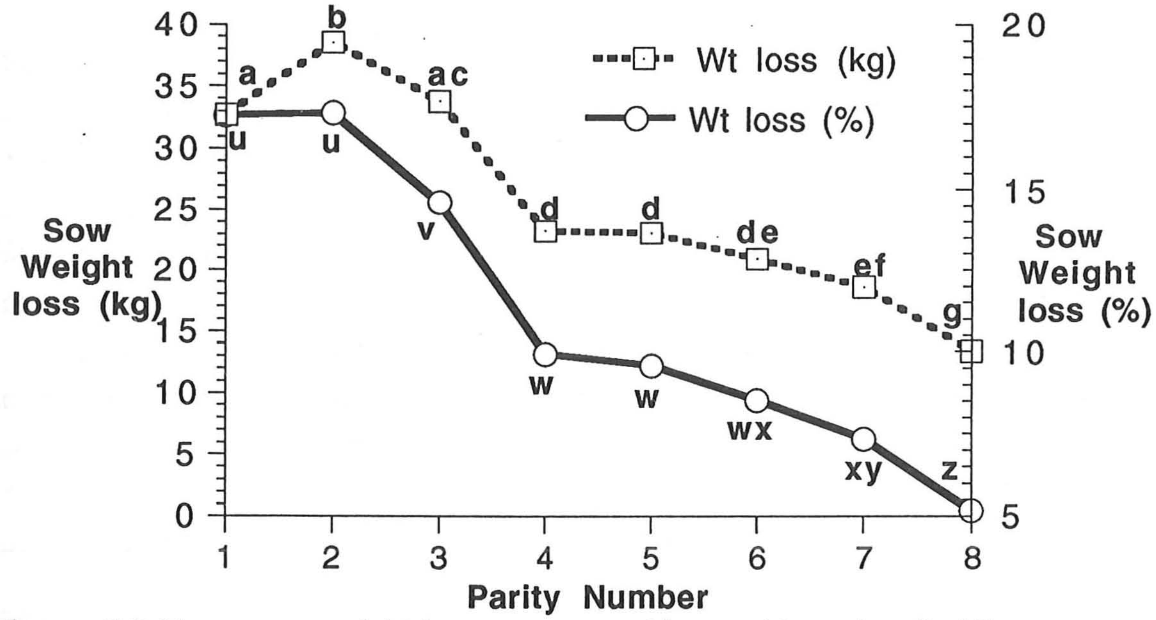


Figure 5.8 Mean sow weight loss over parturition and lactation (in kilograms and as a percentage of total bodyweight) for all sows over eight parities. [a,b,c,d,e,f,g] & [u,v,w,x,y,z] Points without a common letter are significantly different at $p<0.05$.

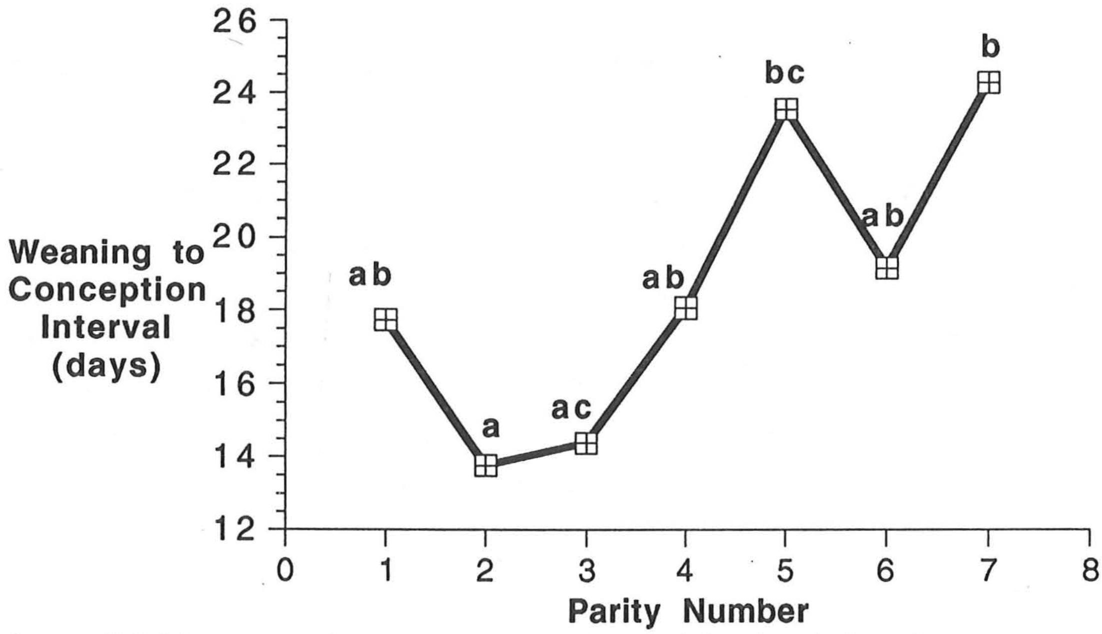


Figure 5.9 Mean weaning to conception interval (in days), for all sows over eight parities. [a,b,c] Points without a common letter are significantly different at $p<0.05$.

5.4.2 Discussion

In general, the results reflect what is already known about the effects of parity number on production. Commercial farms operate a continual herd replacement policy, which will see a turnover of approximately 35-45% of sows in the herd per year. Thus, sows are effectively being sent for culling following weaning of the fifth or sixth litter. After this, as these results demonstrate, production begins to decline dramatically. The mean number of piglets born alive per litter (see Figure 5.2), climbs steadily to a peak at fifth parity of 11.84, but then falls, with a dramatic drop from 11.02 at seventh parity to 9.75 at eighth parity. For the commercial producer, this indicates that it may be financially viable to keep sows which consistently yield large litters past fifth parity. However, once the sow has reached seventh parity, it is likely that litter size will be greatly reduced regardless of previous production, and consequently, the sow should be culled.

The decision to cull can be supported by a number of other production parameters. The mean number of piglets born dead per litter (see Figure 5.3) rises steadily as parity number increases from a low (0.419) at first parity to a high (1.066) at seventh parity. There is also a large increase in percentage piglet mortality (see Figure 5.6) from a low (8.56%) at second parity to a high (19.19%) at eighth parity. This may be due to factors such as the increase in sow weight and size which results is less control during standing and lying. Also, there is a steady decrease in average piglet birthweight (see Figure 5.5) so there may be a tendency for a higher proportion of piglets to be born below the critical 1kg birthweight which predisposes them to death as a result of starvation.

This decrease in numbers born alive and increase in mortality, combine to give a large decrease in number of piglets weaned per litter (see Figure 5.7), falling from a high (10.32) at fifth parity to a low (7.88) at eighth parity. The weaning to conception interval (see Figure 5.9) increases from a low (13.78 days) at second parity to a high (24.28 days) at eighth parity, which effectively decreases the number of litters per sow per year from 2.45 down to 2.29. Thus, eighth parity sows are taking longer to produce litters, giving birth to fewer alive and more dead, and then having more die and ultimately fewer weaned than sows at any other parity, including gilts.

Also of interest is the pre-partum to post-weaning sow weight loss, which can be attributed to two sources: 1) weight of litter, afterbirth etc. 2) weight loss as a consequence of milk production. Both of these will be dependent on the litter size, and it could therefore be expected that the weight loss (kg) graph profile (see Figure 5.8) will mirror the graph profiles of the number born alive, the total litter weight and the number of piglets weaned which are generally similar.

However, the graph shows a steady decline, which may point to feeding irregularities or to a gradual decrease in milk yield as parity number increases. If this is the case, it could be a further factor in the increase in piglet mortality. The graph profile of weight loss (%) (Figure 5.8) is expected, as sow body weight increases continually upto sixth or seventh parity and thus even if kilogram weight loss remained at a constant level, percentage weight loss would decline.

5.5 Whole herd figures by dry sow system

In this section, the production results are presented in terms of dry sow system only, with no distinction in terms of farrowing system. Again, all eight parities were included in statistical analysis which was carried out using ANOVA as above.
The total number of farrowings analysed for each system were: 1) Stalls - 88 farrowings, 2) Small Groups - 120 farrowings, and 3) Large Group - 296 farrowings.

5.5.1 Results

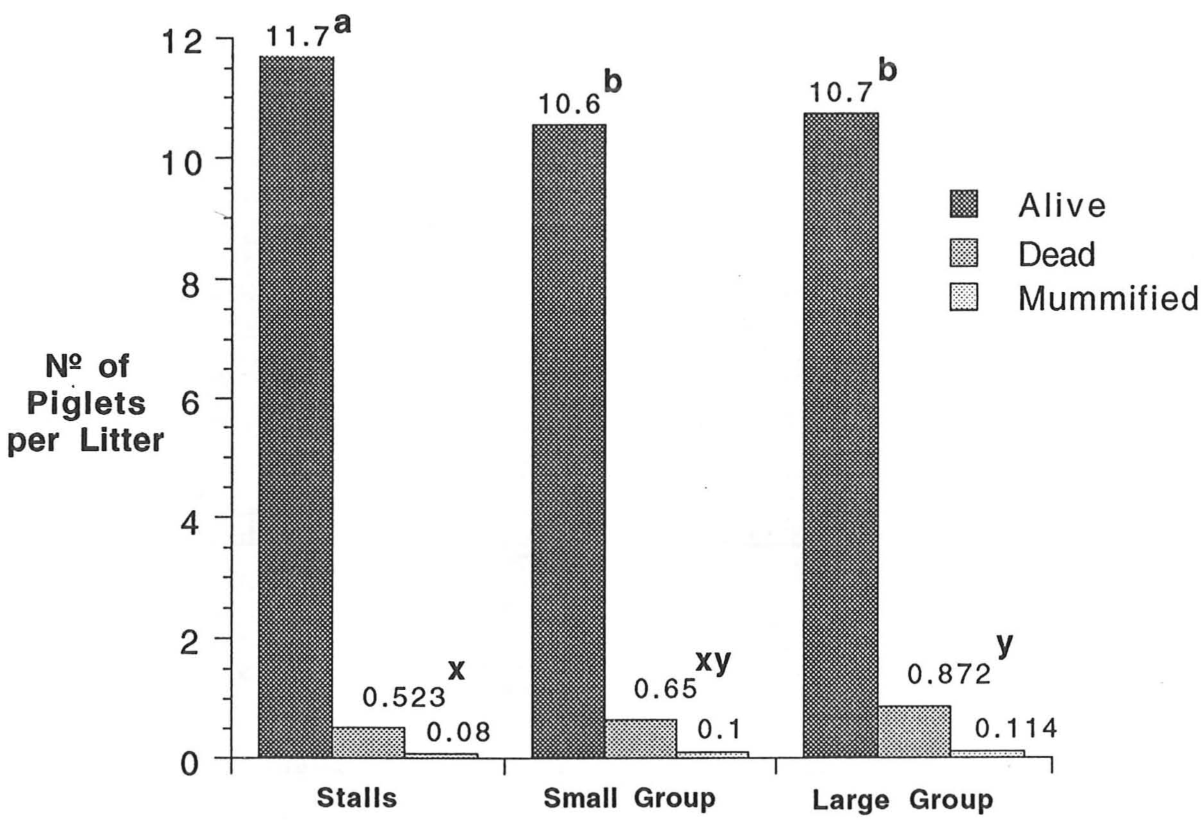


Figure 5.10 Mean number of piglets born alive, dead and mummified per litter, for sows from different dry sow systems, over eight parities. a,b & x,y Values without a common letter are significantly different at $p<0.05$.

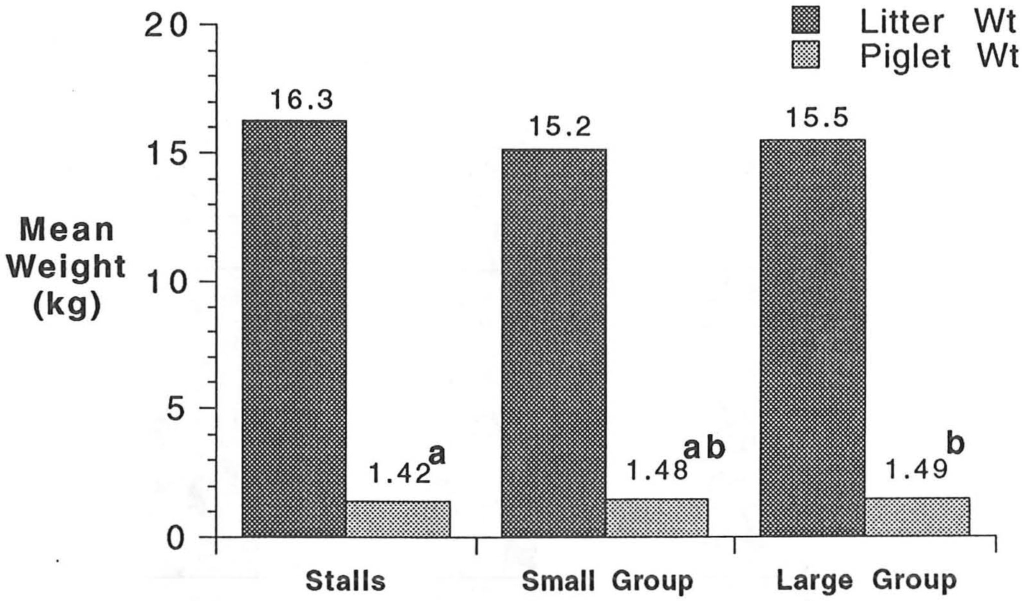


Figure 5.11 Mean total live litter weight and live piglet weight for sows from different dry sow systems, over eight parities. [a,b] Values without a common letter are significantly different at $p<0.05$.

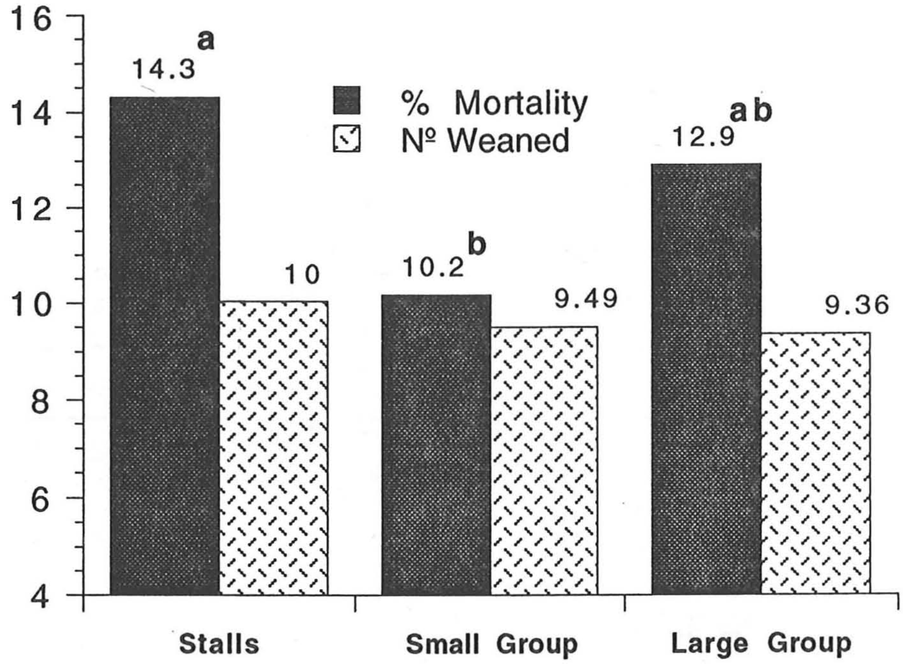


Figure 5.12 Mean percentage piglet mortality and number of piglets weaned per litter, for sows from different dry sow systems, over eight parities. [a,b] Values without a common letter are significantly different at $p<0.05$.

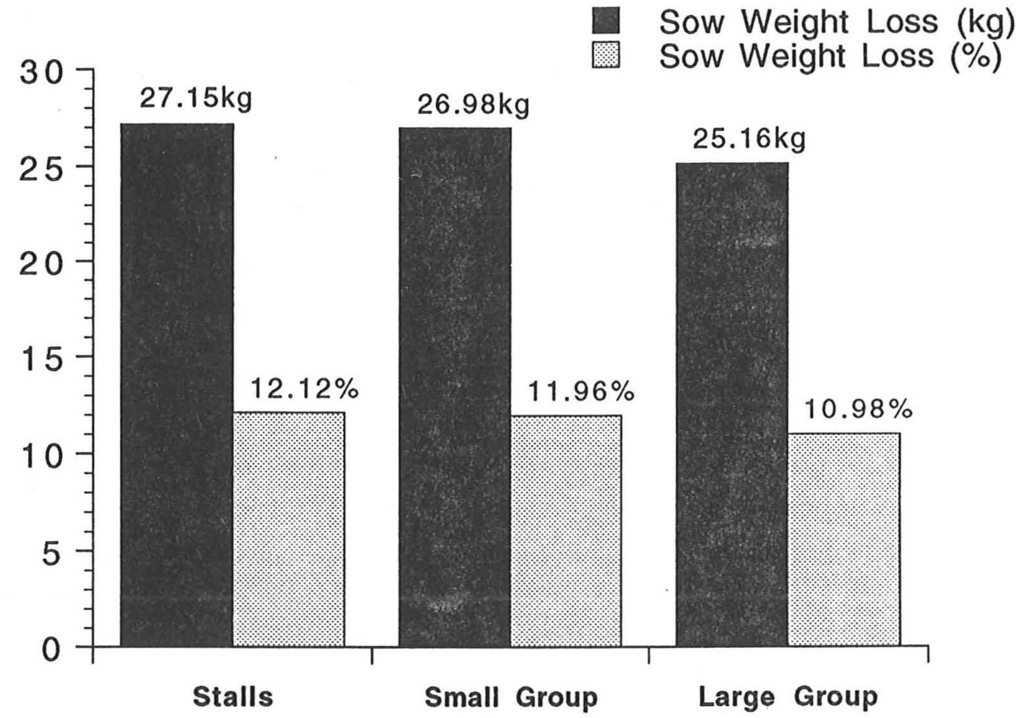


Figure 5.13 Mean sow weight loss over parturition and lactation (in kilograms and as a percentage of total bodyweight) for sows from different dry sow systems, over eight parities.

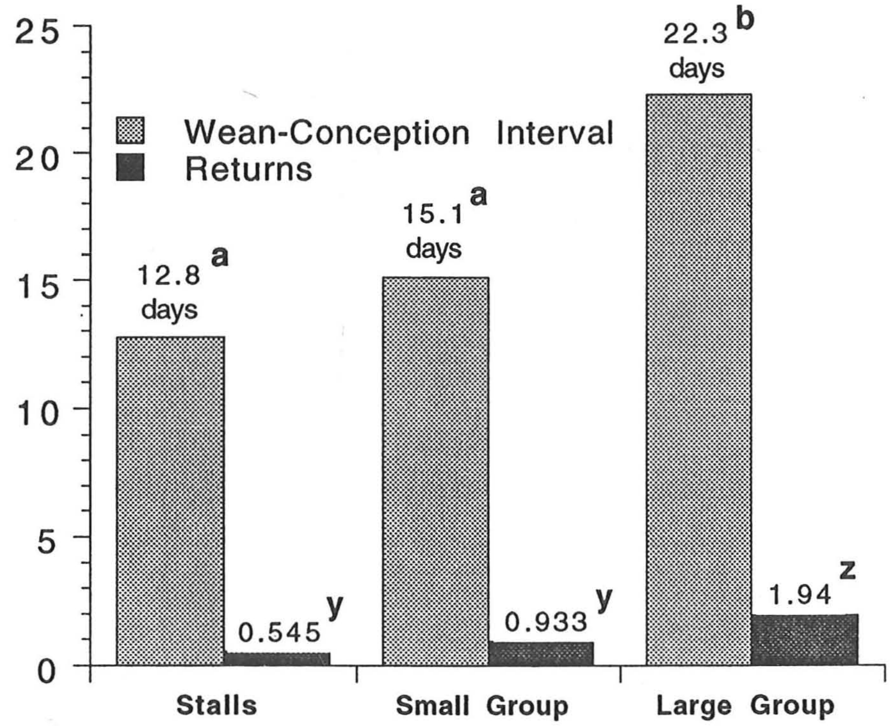


Figure 5.14 Mean weaning to conception interval (days) and average number of returns to service per sow, for sows from different dry sow systems, over eight parities. a,b & y,z Values without a common letter are significantly different at $p<0.05$.

5.5.2 Discussion

Comparison by dry sow system raises a number of interesting points. Although the consensus of opinion is that permanent stalls are detrimental to the welfare of the sows kept in them, there is little evidence of this in terms of the production figures presented here. The mean litter size (see Figure 5.10) is substantially better than those produced by sows housed in the group housing systems. Stall-housed sows gave birth to more live piglets (11.7) than sows housed in the small groups (10.6) or the large group (10.7) and fewer dead piglets (0.52) than sows from the large group (0.87).The other areas of advantage over the large group system, are in the weaning to conception interval and in the number of returns to service (see Figure 5.14). Sows kept in the large group had a longer weaning to conception interval (22.3 days) than stall-housed sows (12.8 days) and sows kept in small groups (15.1 days) and also had more returns to service per sow (1.94 vs. 0.55 & 0.93).

These differences in total number born and number of returns to service may possibly be explained in terms of the effect of housing conditions on embryo implantation. After service, group-housed sows are reintroduced into an environment which subjects them to aggression during re-establishment of the social hierarchy. Social stress at this time may cause hormonal disturbances and result in an increase in the number of embryos which are rejected by the uterine lining (Varley, 1981), thus reducing total litter size. Severe upsets may cause loss of all the embryos and the sow will subsequently return to service. The dynamic nature of the large group results in a greater prevalence of severe aggression than is found within the comparatively static small groups. This difference in levels of aggression may be the cause of the higher number of returns to service seen among sows from the large group. The longer weaning to conception interval for sows from the large group is a consequence of this higher incidence of returns.

However, the production advantages of stall-housed sows do not carry over to the number of piglets weaned because of the higher percentage piglet mortality. For stall-housed sows, piglet mortality was 14.3% which was significantly higher than the 10.2% recorded for sows from the small group system. There was no significant difference in the number of piglets weaned for all three systems. The reasons for this higher mortality may be partially explained in terms of individual piglet weight. Stall-housed sows gave birth to the piglets with the lowest average birthweight (1.42kg) which may result in a greater number of piglets being non-viable as stated in Section 5.4.2. Another contributory factor may be that of less controlled standing and lying as a consequence of the lack of muscular fitness imposed by confinement.

There were no significant differences between dry sow systems in terms of sow weight loss over the pre-partum to post-weaning period. As stated in the previous section, this loss may be attributed to litter weight and energy consumption during lactation. Although stall-housed sows are giving birth to larger litter numbers, there is no difference in litter weight. There is also no significant difference in the number of piglets weaned, so that stall-housed sows have little extra lactation demand.

5.6 Whole herd figures by farrowing system

In this section, the production results are presented in terms of farrowing system only. There was no distinction between sows from different dry sow systems, and the results were analysed using a Student's t-Test run on Statview SE+Graphics software.
The total number of farrowings for each system were: 1) Pens = 168, 2) Crates = 336.

5.6.1 Results

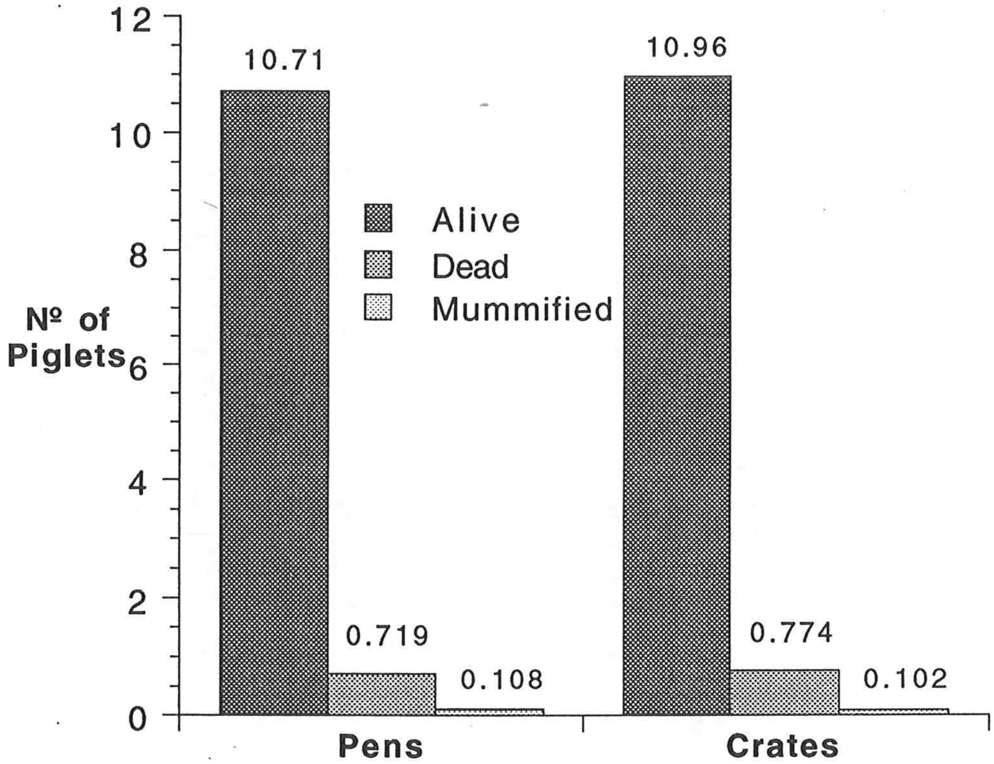


Figure 5.15 Mean number of piglets born alive, dead and mummified per litter, for sows in different farrowing systems, over eight parities.

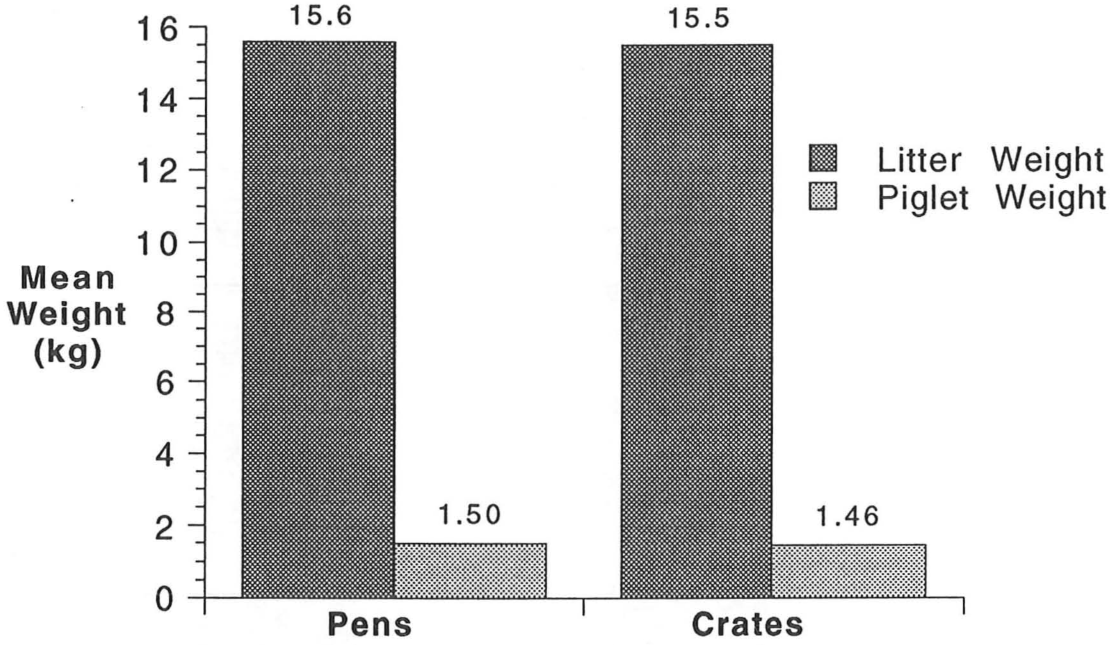


Figure 5.16 Mean total live litter weight and average live piglet weight for sows in different farrowing systems, over eight parities.

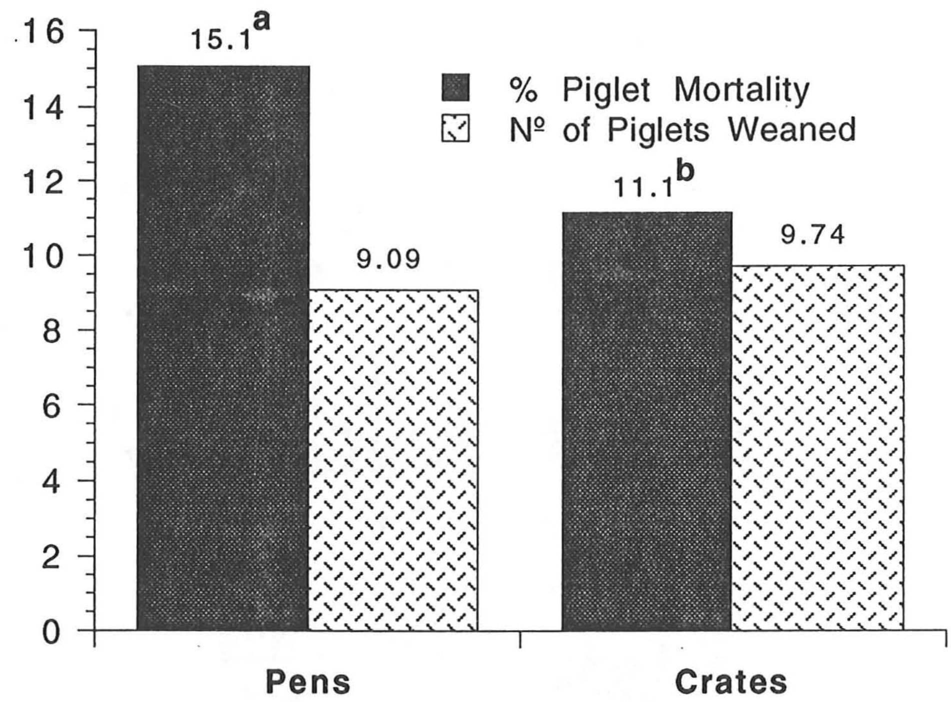


Figure 5.17 Mean percentage piglet mortality and average number of piglets weaned per litter for sows in different farrowing systems, over eight parities. [a,b] Values without a common letter are significantly different at $p<0.05$.

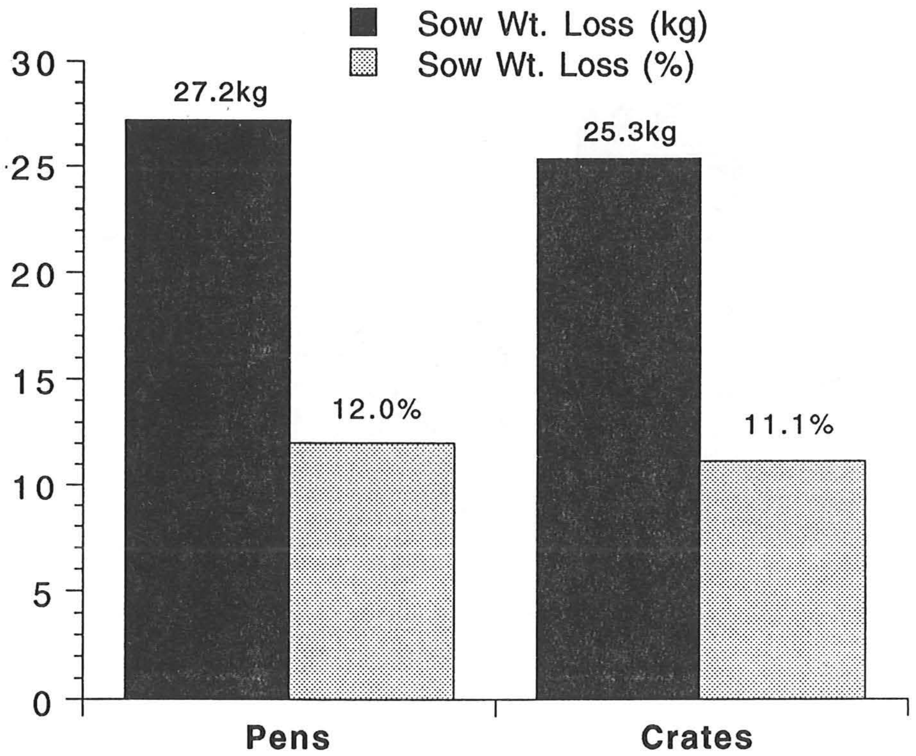


Figure 5.18 Mean sow weight loss over parturition and lactation (in kilograms and as a percentage of total bodyweight) for sows in different farrowing systems, over eight parities.

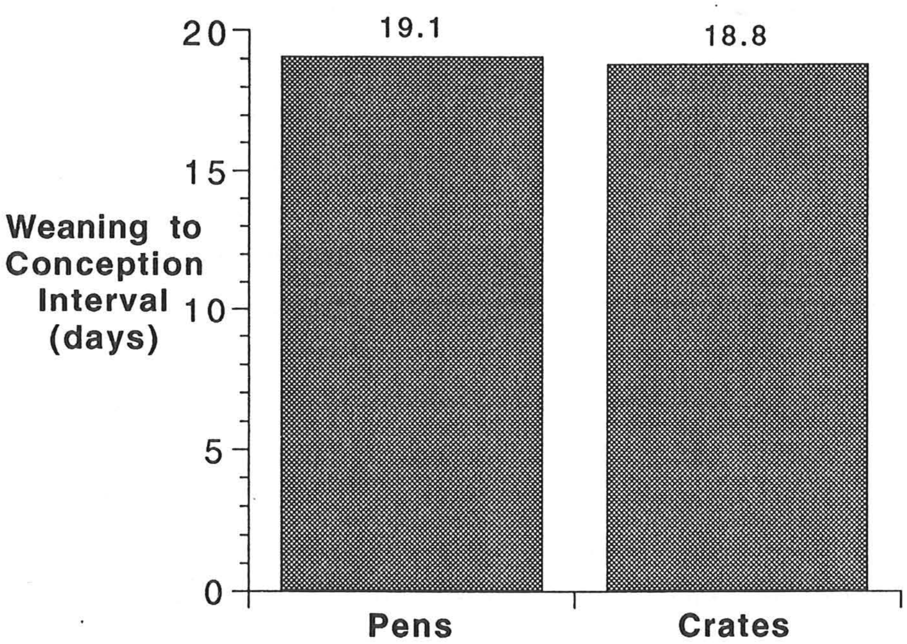


Figure 5.19 Mean weaning to conception interval (days) for sows in different farrowing systems, over eight parities.

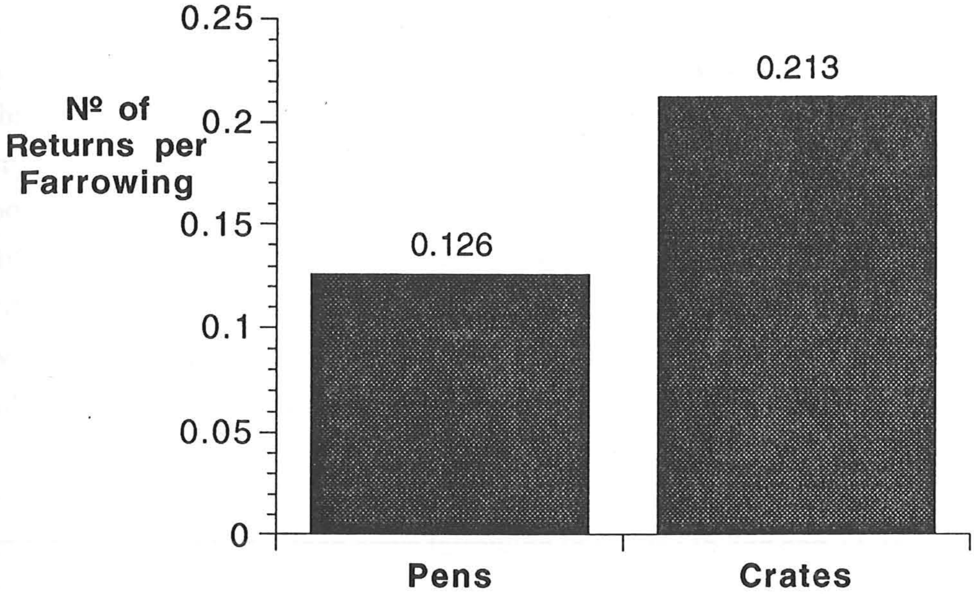


Figure 5.20 Mean number of returns to service per sow per farrowing in different farrowing systems, over eight parities.

5.6.2 Discussion

There were no differences in mean litter size between farrowing systems (see Figure 5.15). This is fairly expected as actual litter size has already been pre-determined before the sows enter the farrowing systems. Although there is a tendency for sows farrowing in crates to give birth to more live piglets (10.96 vs. 10.71), this is purely coincidental with total litter size being slightly larger. If there was an element of effect of the farrowing system on litter composition, it would be expected that any increase in number born alive would be balanced by a decrease in the number born dead. However, this is not the case and numbers born dead and mummified in each farrowing system, are very similar.

There were no significant differences in total live litter weight (15.6kg vs. 15.5kg) or in individual piglet weight (1.50kg vs. 1.46kg) (see Figure 5.16). Again, differences in these variables are more likely to be as a consequence of dry sow system, as seen in the previous section, rather than farrowing system. As there is an even distribution of sows from different dry sow systems across the farrowing systems, any differences in production in this section will be due to farrowing condition alone.

One area where there is a difference between farrowing systems is in percentage piglet mortality (see Figure 5.17). Sows farrowing in pens had a higher mortality figure (15.1%) than sows farrowing in crates (11.1%) As the literature review indicated, the majority of studies on farrowing systems have recorded higher mortality rates in open systems, and the possible reasons for this will be discussed in greater detail later. Together with this difference in mortality between the two systems, there was also a tendency for sows in crates to wean more piglets (9.74) than sows in pens (9.09). These results, of course, add weight to the argument for the continued use of crates above alternative systems which allow the sow greater freedom.

Sows farrowing in pens tended to lose more weight, both as an absolute value (27.2kg) and as a percentage (12%), than sows farrowing in crates (25.3kg and 11.1% - see Figure 5.18). This occurred even though there was no difference in litter weight, and crated sows tended to wean more piglets, penned sows lost more weight over the farrowing/lactating period. Therefore, this tendency is most likely due to the increased amount of exercise permitted in pens.

There were no significant differences between crates and pens in terms of weaning to conception interval (18.8 days vs. 19.1 days - see Figure 5.19) or mean number of returns to service per farrowing (0.213 vs. 0.126 - see Figure 5.20). However, the higher number of returns to service by sows which have farrowed in crates may highlight an adverse affect of confinement during this period.

5.7 Whole herd figures by six treatments

In this section, the results are presented in terms of the treatments specified in the introduction. Thus, the effects of both dry system and farrowing system are taken into account.

The total number of farrowings for each system were: 1) Stl/Pens = 168, 2) Stl/Crates = 336, 3) SGrp/Pens = 131, 4) SGrp/Crates = 322, 5) LGrp/Pens = 222, and 6) LGrp/Crates = 111.

5.7.1 Results

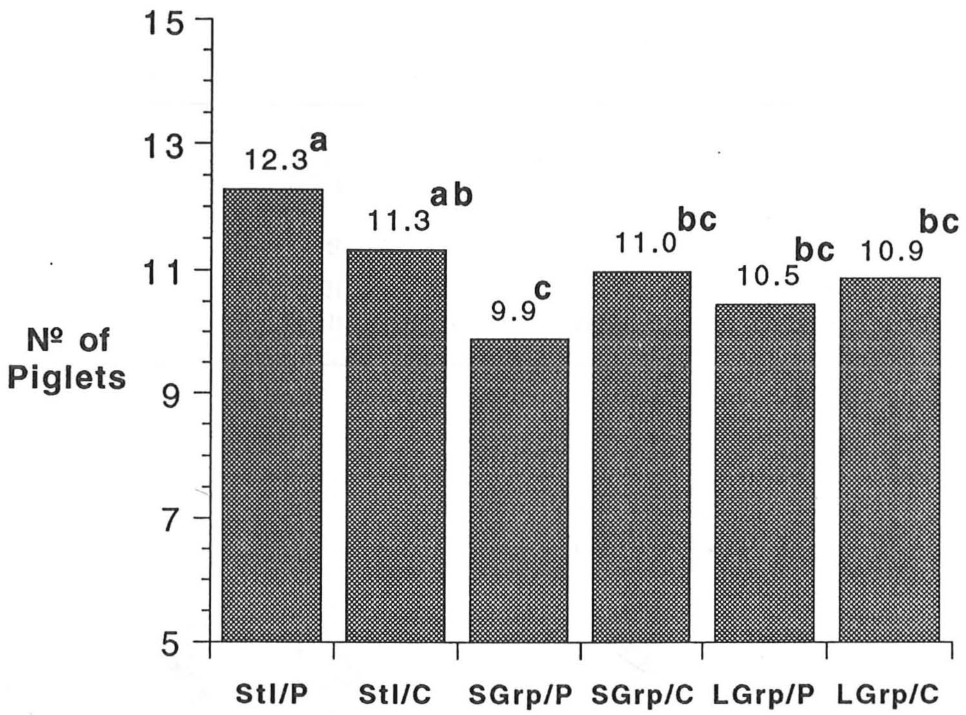


Figure 5.21 Mean number of piglets born alive per litter, for sows in the six different Treatments, over eight parities. a,b,c Values without a common letter are significantly different at $p<0.05$.

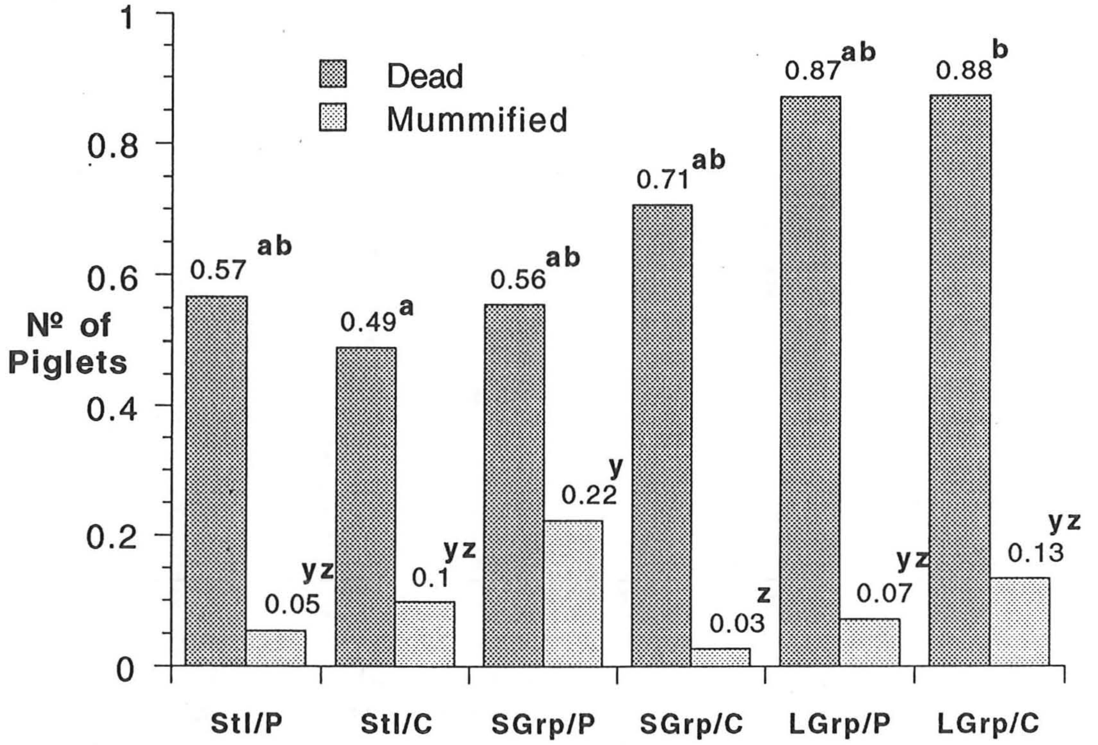


Figure 5.22 Mean number of piglets born dead and mummified per litter, for sows in the six different Treatments, over eight parities. a,b & y,z Values without a common letter are significantly different at $p<0.05$.

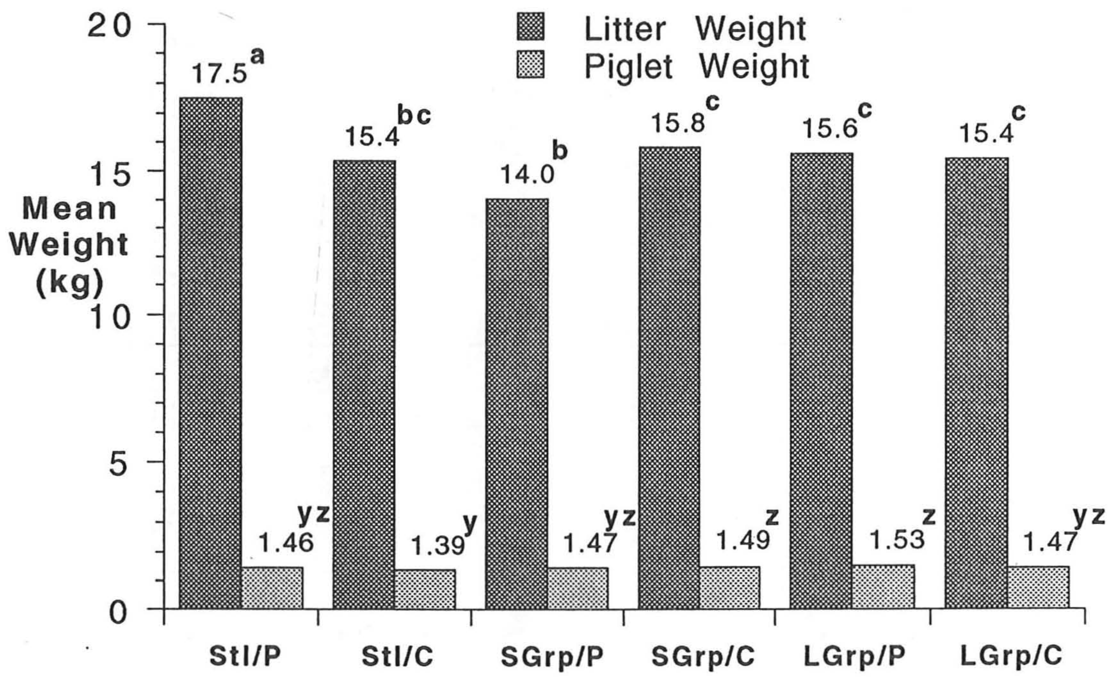


Figure 5.23 Mean total live litter weight and average live piglet weight for sows in the six Treatments, over eight parities. a,b,c & y,z Values without a common letter are significantly different at $p<0.05$.

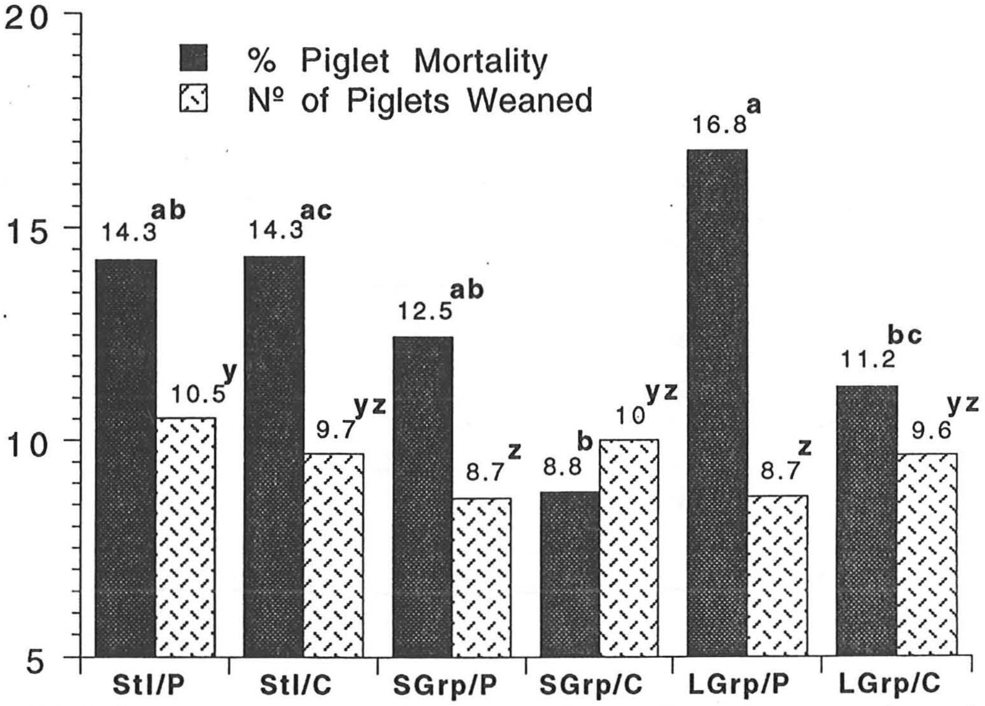


Figure 5.24 Mean percentage piglet mortality and average number of piglets weaned per litter, for sows in the six Treatments, over eight parities. a,b,c & y,z Values without a common letter are significantly different at $p<0.05$.

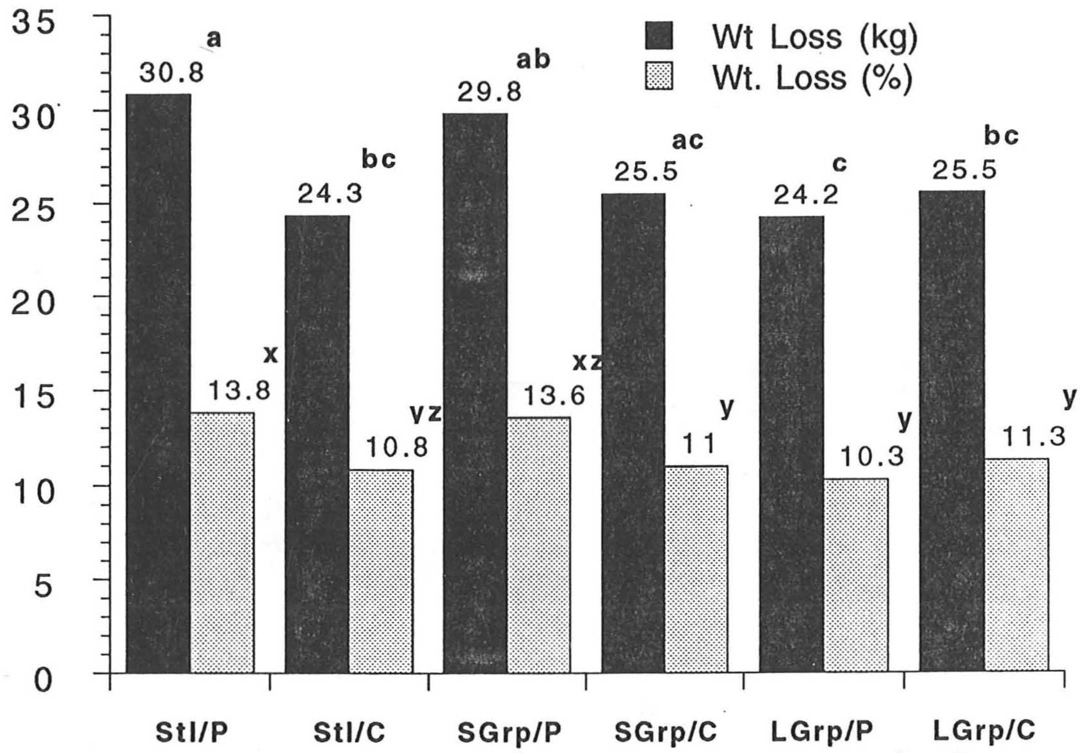


Figure 5.25 Mean sow weight loss over parturition and lactation (in kilograms and as a percentage of total bodyweight), for sows in the six Treatments, over eight parities. a,b,c & x,y,z Values without a common letter are significantly different at $p<0.05$.

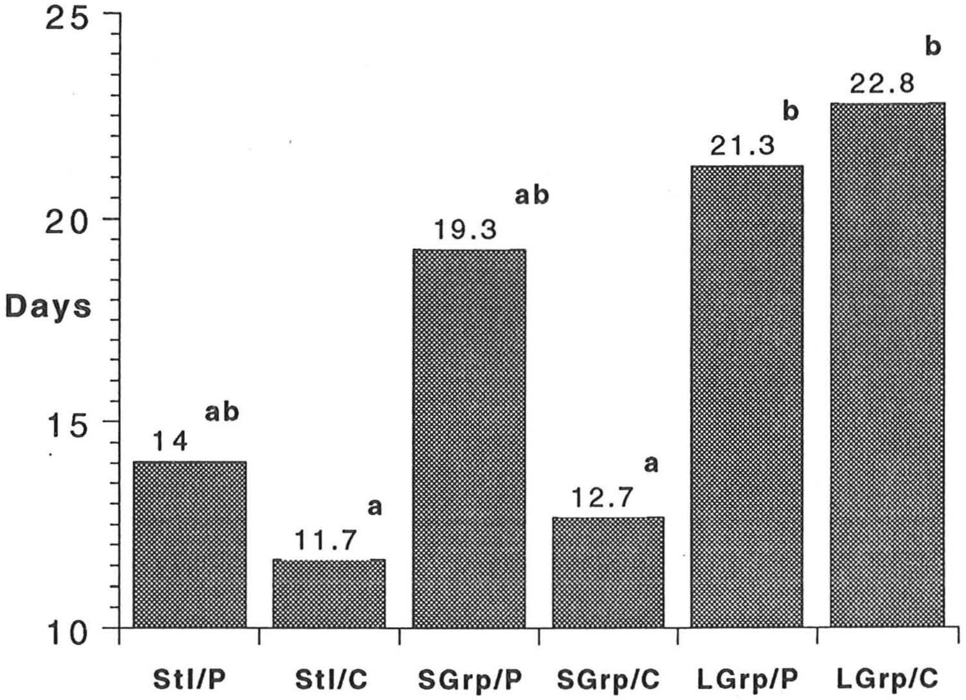


Figure 5.26 Mean weaning to conception interval (days) for sows in the six Treatments, over eight parities. a,b Values without a common letter are significantly different at $p<0.05$.

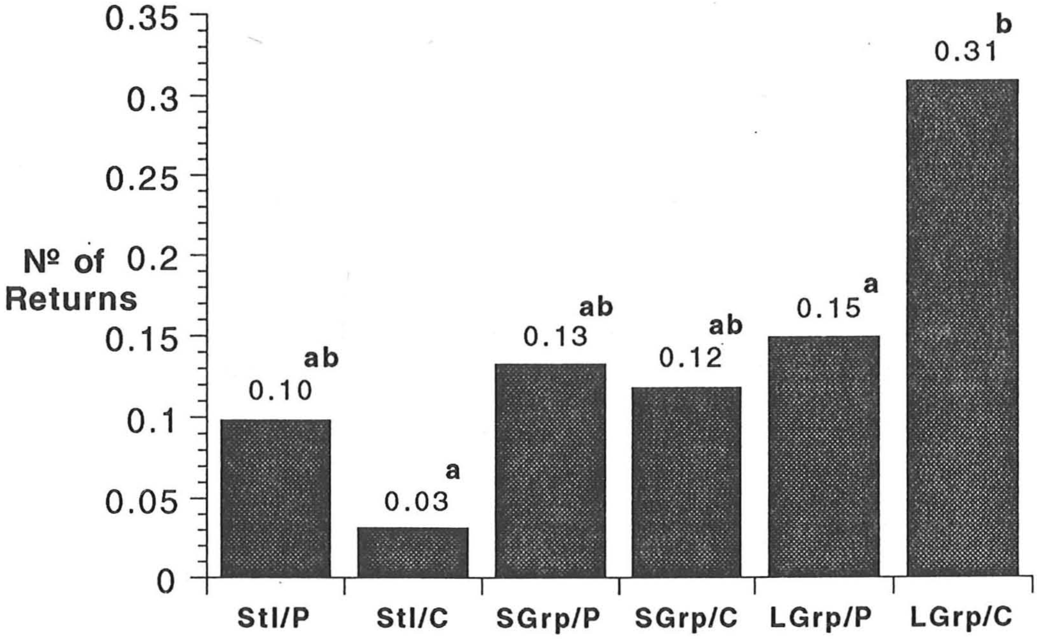


Figure 5.27 Mean number of returns to service per sow per farrowing in the six Treatments, over eight parities. a,b Values without a common letter are significantly different at $p<0.05$.

5.7.2 Discussion

Analysis by treatment does highlight differences that would otherwise pass unnoticed if looking at the results purely in terms of dry sow or farrowing system.

Litter size would appear to be unaltered by the combination of dry sow and farrowing differences (see Figures 5.21 & 5.22). There are no differences in numbers born alive or dead between sows from the same dry sow system farrowing in pens or farrowing in crates. Stall house sows farrowing in pens gave birth to more live piglets than sows from both group systems farrowing in pens and crates. Also, sows from the large group farrowing in crates gave birth to more dead piglets than stall house sows farrowing in crates, but as we have seen in Section 5.5, these differences can be explained as a result of differences due to dry sow system.

There was a significant difference between sows from the small group system farrowing in pens and the same sows farrowing in crates, in the number of piglets born mummified. This is not attributable to the effect of the farrowing condition, but can be explained by disease. These sows suffered from infection during the third parity, and a number of pregnancies were aborted. The majority of those that did not abort, subsequently farrowed in pens, and gave birth to a high number of mummified piglets, resulting in this difference.

Differences in total live litter weight somewhat reflect the differences in number of piglets born alive (see Figures 5.21 & 5.23). The heaviest litters were born to stall-housed sows farrowing in pens (17.5 kg), but these sows also gave birth to the largest litters. Thus, average piglet weight was fairly similar for all six treatments, but with stall-housed sows farrowing in crates giving birth to the lightest (1.39 kg).

The percentage piglet mortality figures show interesting differences (see Figure 5.24). The sows from both of the group-housed systems had markedly higher piglet mortality in the pens (12.5% & 16.8%) compared with the crates (8.8% & 11.2%), whereas the stall-housed sows had similar piglet mortality in both farrowing conditions (14.2% vs. 14.3%). From these figures, it would appear that loose-housed sows benefit from the restriction of movement imposed by crates, in terms of piglet mortality, whereas sows housed permanently in confinement do not. These differences may be explained in part by the differences in muscular "fitness" which is dependent on the amount of exercise permitted by the dry sow system. However, another factor may be that of birthweight, and, as noted above, stall-housed sows farrowing in crates gave birth to the lightest piglets, which may render them more susceptible to neonatal death. The problems of piglet mortality and possible causes will be discussed in detail in Chapter 9.

One consequence of the differences in litter size and the percentage piglet mortality, is that stall-housed sows farrowing in pens wean significantly more piglets (10.5, see Figure 5.24) than the loose-housed sows farrowing in pens (8.6 & 8.7). There are no differences between dry sow systems when farrowing in crates. Also, there are differences in pre-partum to post-weaning sow weight loss (see Figure 5.25). The differences between stall-housed sows farrowing in crates and stall-housed sows farrowing in pens would be expected. In pens, the total litter weight is higher as is the number of piglets weaned. Thus, the lactational demand is greater, and this coupled with the likelihood of a greater amount of exercise will result in greater weight loss (13.8% vs. 10.8%).

For sows from the small groups, again, more weight is lost when farrowing in pens (13.6% vs. 11.0%). This time, however, litter weight and number weaned are higher in crates and thus sow weight-loss could be expected to be higher for these sows. The difference must therefore be explained by higher calorific utilisation as a result of exercise and/or raised metabolic rate. For sows from the large group, there is no difference in litter weight and the number of piglets weaned is marginally higher in crates. Thus, it would also be expected that more weight would be lost when farrowing in pens, in line with the other dry sow systems. However, there is no significant difference, and in fact sows from the large group, farrowing in crates have a tendency to lose the greater amount of body weight (10.3% vs. 11.3%). This must indicate that these crated sows have higher calorific utilisation which cannot be explained in terms of amount of exercise.

The average weaning to conception interval differs between treatments (see Figure 5.26) with stall-housed sows and sows from the small groups, farrowing in crates having the lowest (11.7 & 12.7 days respectively) and sows from the large group farrowing in pens and crates having the highest (21.3 & 22.8 days respectively). For stall-housed sows and sows from the small groups, farrowing in pens, the interval is higher than the crate figure, but not significantly so (14.0 & 19.3 days respectively).

To be explained, these figures must be looked at in conjunction with number of returns to service (see Figure 5.27). For stall-housed sows, the slightly higher average interval can be attributed to a higher number of returns. For the sows from the small groups, the number of returns are the same after farrowing in pens (0.13) or crates (0.12). Thus the difference in average interval must be attributed to other factors. Likewise, the average interval in sows from the large group is the same, but the number of returns to service is significantly higher for crated sows (0.31) than for penned sows (0.15). Therefore, after farrowing in pens, loose-housed sows would appear to take longer to return to œstrus, which may indicate a degree of hormonal imbalance.

5.8 Overall discussion

Detailed study of the herd production figures reveals that possible welfare problems exist in all three dry sow systems, both farrowing systems, and in all combinations of the two. There is certainly no combination that consistently out-performs any other in production terms.

Sows housed in stalls did appear to be the most productive and the least affected by the different farrowing systems. They consistently produced significantly larger litters which would indicate a low level of hormonal upset at the time of follicular maturation (Hennessey & Williamson, 1983), or at the time of embryo implantation and early development (Varley, 1981). They also had the shortest weaning to conception interval which contradicts a large number of studies that demonstrate confined sows to take longer to return to œstrus (Sommer, 1979, Sommer et al, 1982, Hemsworth et al, 1982). The number of returns to service was lowest, as seen in studies by Maclean (1969) and Hansen & Vestergaard (1984). However, they also gave birth to significantly lighter piglets, which again contradicts the result of another study (Den Hartog et al, 1993), and had significantly higher piglet mortality and high sow weight loss over the lactation period. There was subsequently no significant difference in the number of piglets weaned between dry sow systems, and thus in monetary terms, the better production figures of stall-housed sows, may be of minimal advantage.

The sows from the small group system were also fairly productive but some parameters were variable depending on type of farrowing system. Overall, they had the lowest piglet mortality, a low weaning to conception interval, low number of returns to service and heavy individual piglet weight. However, they had the lowest total litter size and a high percentage loss of total body weight over the lactation period.

The sows from the large group system do appear to have the worst production figures in a number of areas, but again certain parameters were variable depending on farrowing system type and there also seemed to be a greater degree of individual variation, with some poor producing sows pulling the figures down. Although they gave birth to the heaviest piglets, percentage mortality was fairly high, as was the number of piglets born dead which can indicate acute stress around the time of parturition (Bäckström, 1973, Gustaffson, 1982). This resulted in the number of piglets weaned being the lowest of the three systems, but not significantly so. The weaning to conception interval and the number of returns to service were also significantly higher than the other two systems, which may be attributable to inter-sow aggression following mixing (Maclean, 1969, Hansen & Vestergaard, 1984).

The type of farrowing system will only affect some of the measured parameters, and not those such as total litter size and litter weights, which have been largely pre-determined before entry into the farrowing house. One measure that is affected is that of piglet mortality, with higher mortality in pens and therefore less piglets weaned. This is a result that has been demonstrated in a large number of studies (e.g. Aherne, 1982, Collins et al, 1987, Cronin & Smith, 1992a) and is the major argument in the pig industry, in terms of poor litter welfare and also financial loss, for the retention of farrowing crates over alternative systems.

In all other production aspects, farrowing pens perform comparably, and in terms of the average number of returns to service after farrowing in each system, sow in pens tended to return less often than sows in crates (0.126 vs. 0.213). However, this does not result in a longer weaning to conception interval, which demonstrates that sows weaned from pens take longer to return to œstrus than sows weaned from crates.

The majority of production problems do appear to be seen in the sows kept in the large group, but the problems are not exclusive to the large group/crate treatment. Both large group treatments suffer from a disproportionately high number of piglets stillborn. This is an indication of very late intra-uterine death, or indeed death during parturition itself due to anoxia. Sprecher et al (1975) have implicated increased stillborn incidence with prolonged farrowing time, which has been recorded as being longer in sows farrowing in confinement (Bäckström, 1973, Hansen & Vestergaard, 1984). The high incidence in both farrowing systems may point more towards some form of hormonal "upset" as a result of the move to farrowing conditions. The fact that only the sows from the large group show this higher incidence may be because they suffer the highest degree of social isolation before they would actively seek separation from the herd prior to parturition.

Other problem areas specifically for sows from the large group, farrowing in crates, are those of pre-partum to post-weaning sow weight loss and also the very high number of returns to service. As discussed earlier, the sows from the other dry sow systems lost more weight in the pens than the crates. This was mostly attributed to greater calorific utilisation as a consequence of more exercise. In the sows from the large group, this disparity in sow weight loss may indicate a long-term response to the stress of confinement. This hypothetical response may also be responsible for the increased number of returns to service for these sows. The increase cannot be explained purely in terms of aggression during mixing, because this would not account for the difference recorded between the large group treatments.

The farrowing pens appear to give rise to problems for sows from both group-housing systems in terms of longer weaning to conception intervals and increased piglet mortality. The longer weaning to conception interval is not attributable to more returns to service pushing up the average value, but rather to a longer interval between weaning and first œstrus. This would seem to indicate that group sows that have farrowed in pens show a greater stress response to enforced weaning, than group sows that have farrowed in crates. This is perhaps a consequence of the fact that these penned sows have a greater opportunity to exhibit maternal behaviour and form stronger maternal bonds than crated sows. Any greater response may result in increased cortisol levels which may promote anœstrus (Meredith, 1982).

Piglet mortality is a complex problem, and one which is very costly to the pig industry, in both welfare and financial terms. There is no single definite cause, but a number of areas have been highlighted as discussed earlier in Section 2.2.3. The greater mortality in pens would seem to highlight the fact that crates somehow compensate for poor maternal behaviour. However, there were also problems of inadequate insulation in the pens during cold winters and therefore a number of piglet deaths that were due to hypothermia may have somewhat "over-inflated" these mortality figures.

The fact that stall-housed sows had similar piglet mortality rates in both farrowing systems is possibly due to a combination of litter size and average piglet weight having a greater influence than environmental factors. As litter size increases, average piglet weight falls nearer to the critical 1kg mark, and within-litter variation also increases. Thus, as the average piglet weight of stall-housed sows farrowing in crates was the lowest, so the susceptibility to higher mortality rates increased.

An important consideration in interpretation of these results is not to bracket the group house systems together. There must be a great difference for the sows, between a small static group of five pen-mates and a large dynamic group of 25-30 pen-mates. Another factor is the presence of individual feeding stalls in the small groups. To some extent, the sows may equate these feeding stalls with farrowing crates. Although the time-scale is vastly different, in both cases the sows are shut in and unable to exit when they wish to do so, the designs are similar and are associated with food. The large group is equipped with an electronic feeder system to which entry and exit is sow-controlled and which is solid-sided and unlike a farrowing crate in appearance. These differences may go some way to explaining the responses that sows from the different dry sow systems have to crates.

CHAPTER 6

The effects of dry sow housing conditions on behavioural responses to farrowing conditions

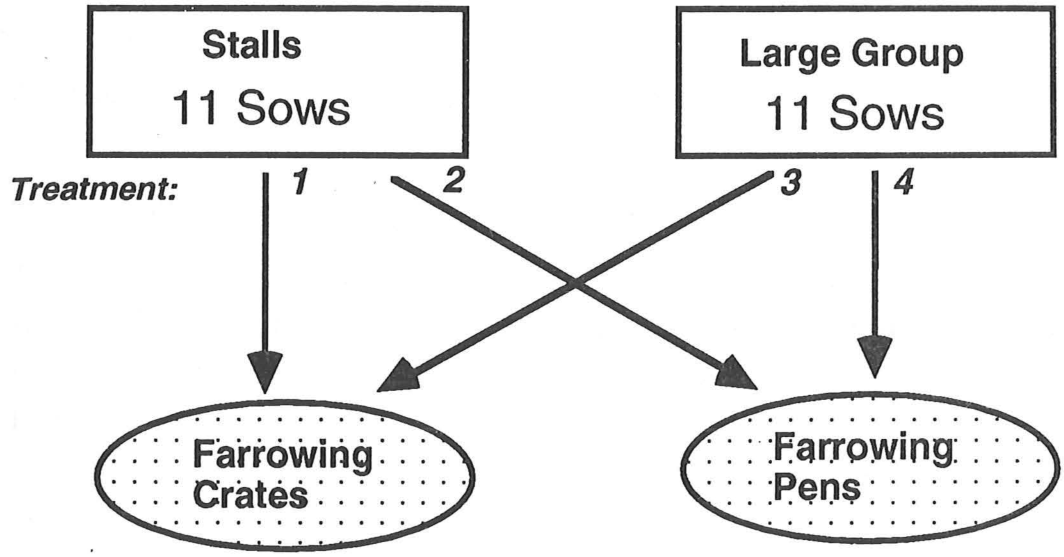
6.1 Introduction

The majority of sows in the United Kingdom farrow in commercial crates, irrespective of the housing system in which they were kept during gestation. Consumer demand is influencing current thinking on intensive husbandry systems and this, together with approaching legislation concerning the ban on stalls and tethers, is forcing the UK pig industry to move further towards group housing for gestating sows. However, there will be no legislation directed against the continued use of farrowing crates, and thus, research needs to assess the effects that this close confinement may have on sows which have previously gestated in an open environment.

Previous research has demonstrated the importance to the sow, of being able to carry out nest-building activity (Jensen, 1989, Zanella & Zanella, 1993). Any farrowing system that restricts the sow's ability to nest-build, will therefore significantly influence her pre-farrowing behaviour and may give rise to anomalous activity. The objective of this study was to determine whether the housing conditions of gestating sows had effects on their behavioural responses to farrowing conditions from entry into the farrowing system, up to the onset of parturition.

6.2 Materials and methods

The study was carried out on the Animal Welfare Group's Pig Unit, using twenty-two Large White X Landrace sows ranging from third to sixth parity. Eleven sows housed in the permanent stalls, and eleven sows loose-housed in the large group system with Electronic Sow Feeder, were each observed over two farrowings; once in an open pen and once in a conventional crate, giving eleven farrowings observed in each of four Treatments (see Figure 6.1). The housing systems have been described previously in Chapter 4.



Treatment 1: Stall-housed sows farrowing in Crates (**S/C**)
Treatment 2: Stall-housed sows farrowing in Pens (**S/P**)
Treatment 3: Group-housed sows farrowing in Crates (**G/C**)
Treatment 4: Group-housed sows farrowing in Pens (**G/P**)

Figure 6.1 Diagram illustrating the four Treatments compared in the study.

Five days before the predicted farrowing date, the sows were removed from the dry sow house, weighed, washed and moved a distance of about 200 metres to the farrowing house. Here they were recorded, using time-lapse video (Panasonic AG-6720A) with integral 24 hour clock, from moment of entry until farrowing had occurred. Production figures were also noted. From the video data, the number of posture changes were recorded, and the average duration and total duration per posture type calculated by reading the inset clock, in three separate 24 hour periods. These periods were:
Period 1: Entry Period - the first 24 hours in the farrowing house.
Period 2: 72-48h Prepartum - the period between 72-48 hours before farrowing.
Period 3: 24-0h Prepartum - the 24 hours immediately preceding farrowing.
Not all sows farrowed on the fifth day after entry into the farrowing house, and in some cases, when farrowing occurred on or before the third day after entry, the Entry Period overlapped with 72-48h Prepartum. In these cases, the 72-48h Prepartum results were omitted from the analysis. The postures recorded were placed into one of four categories:
a) Standing - Sow standing on all four limbs.
b) Sitting - Sow "dog-sitting" on hindlimbs. This category also included kneeling.
c) Lying on Udder - Sow is sternally recumbent with no teats exposed for suckling.
d) Lying with Udder Exposed - Sow is laterally recumbent with teats exposed.
All data were analysed using Analysis of Variance (ANOVA) run on StatView SE+ *Graphics* software.

6.3 Results

6.3.1 Production figures

There were no significant differences in production figures, but, because of small sample sizes, differences would have to have been large to be significant. There were no significant differences in litter size, but there were tendencies for stall house sows to have larger litters in terms of total number of piglets born (12.73 vs. 11.58), and for sows farrowing in crates to have a higher number of piglets born dead (0.86 vs. 0.31) as shown in Figure 6.2.

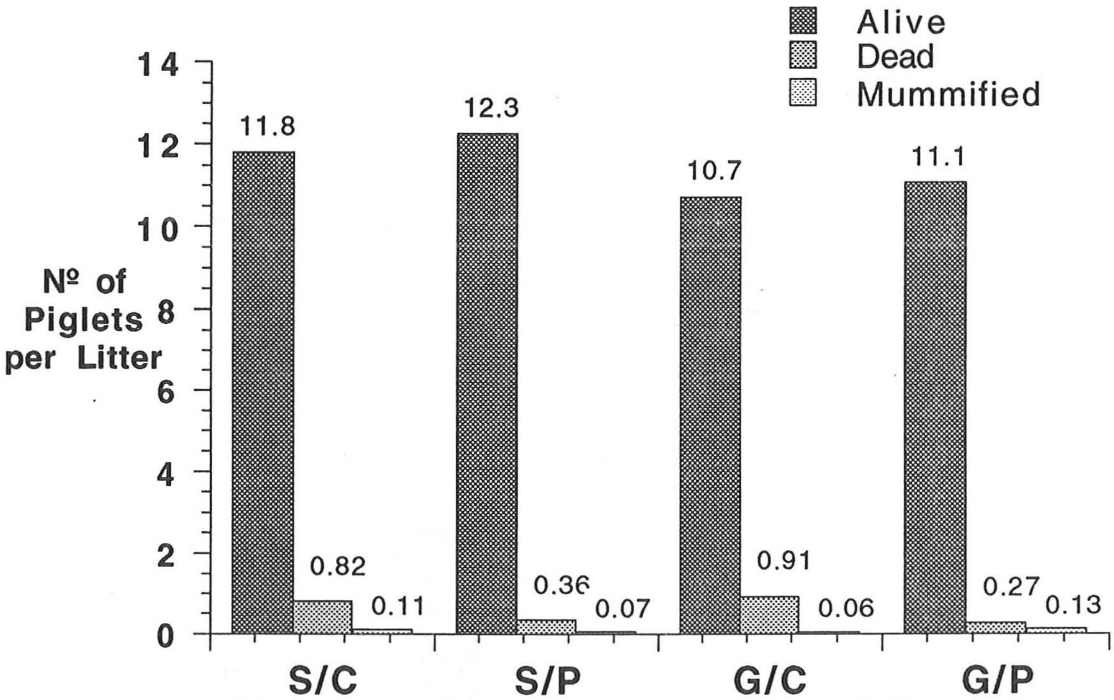


Figure 6.2 Mean number of piglets born alive, dead and mummified per litter, for sows in the four Treatments.

There were no significant differences in total live litter weight or individual piglet weight (see Figure 6.3), but stall-housed sows farrowing in pens tended to give birth to lighter piglets than group-housed sows farrowing in pens (1.41 vs. 1.58).

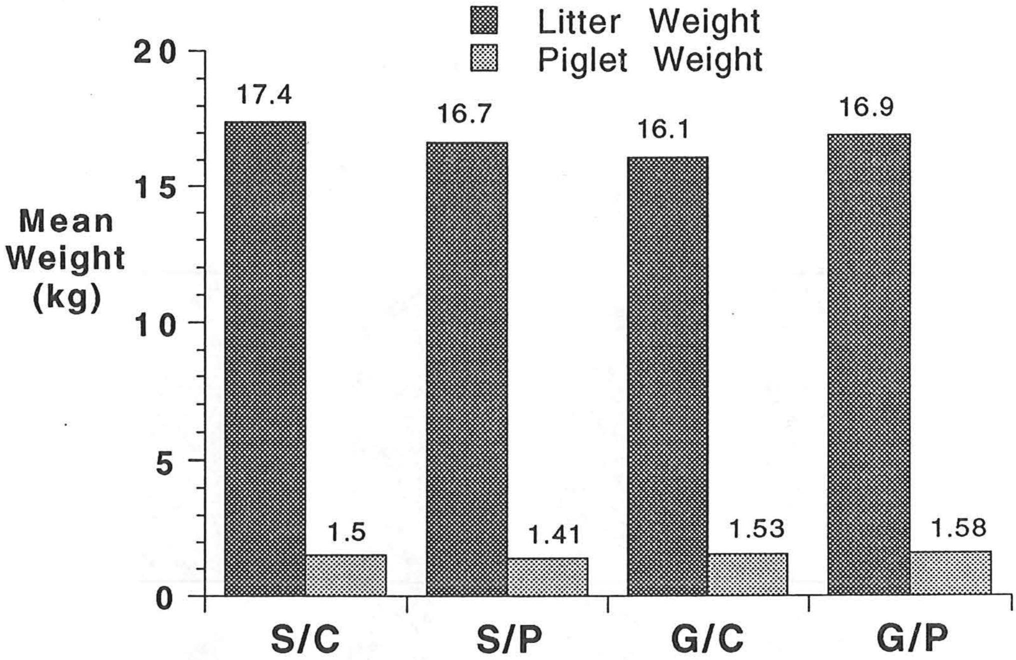


Figure 6.3 Mean total live litter weight and mean live piglet weight, for sows in the four Treatments.

There were no significant differences in percentage piglet mortality or in the number of piglets weaned (see Figure 6.4). Mortality did appear to be slightly higher for stall-housed sows (11.16 vs. 8.28) and also for sows farrowing in pens (10.97 vs. 8.47).

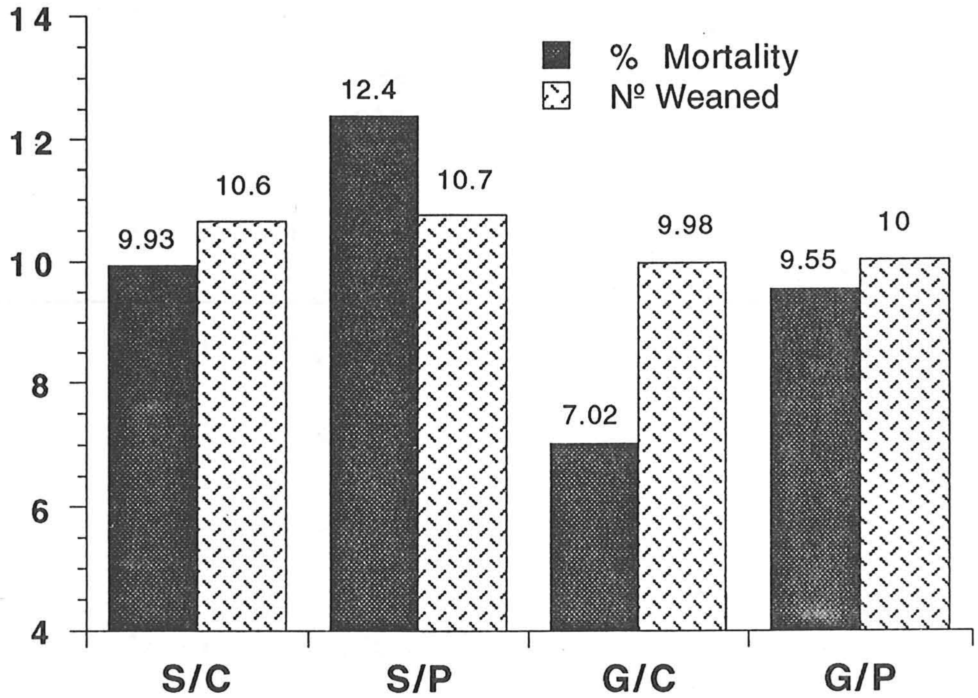


Figure 6.4 Mean percentage piglet mortality and mean number of piglets weaned per litter, for sows in the four Treatments.

There were no significant differences in sow weight loss over the lactational period, both in terms of absolute loss (kilograms) or loss as a percentage of total body weight (see Figure 6.5).

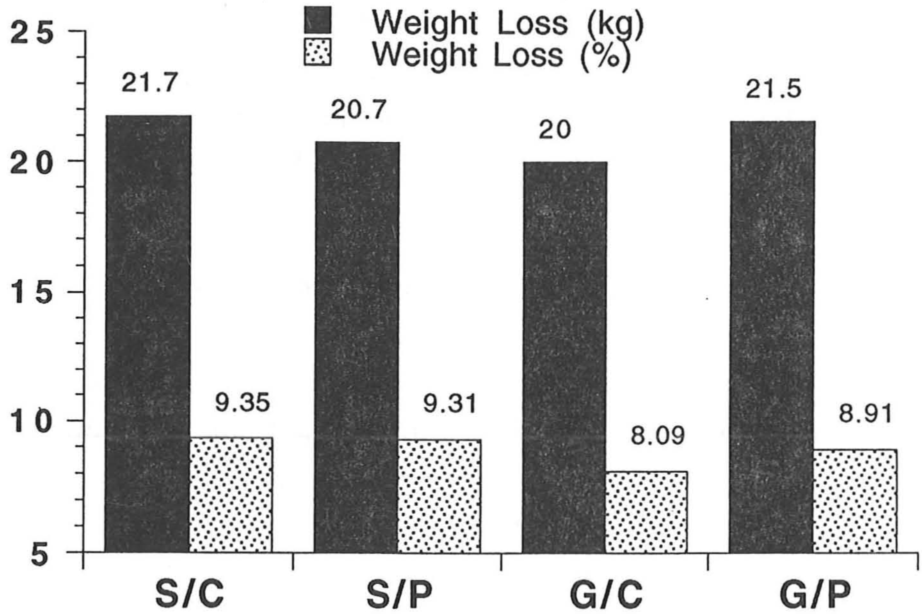


Figure 6.5 Mean sow weight loss over parturition and lactation (in kilograms and as a percentage of total bodyweight) for sows in the four Treatments.

There were no significant differences in weaning to conception interval (see Figure 6.6), but there was a tendency for group-housed sows to have a longer interval (23.3 vs. 13.9).

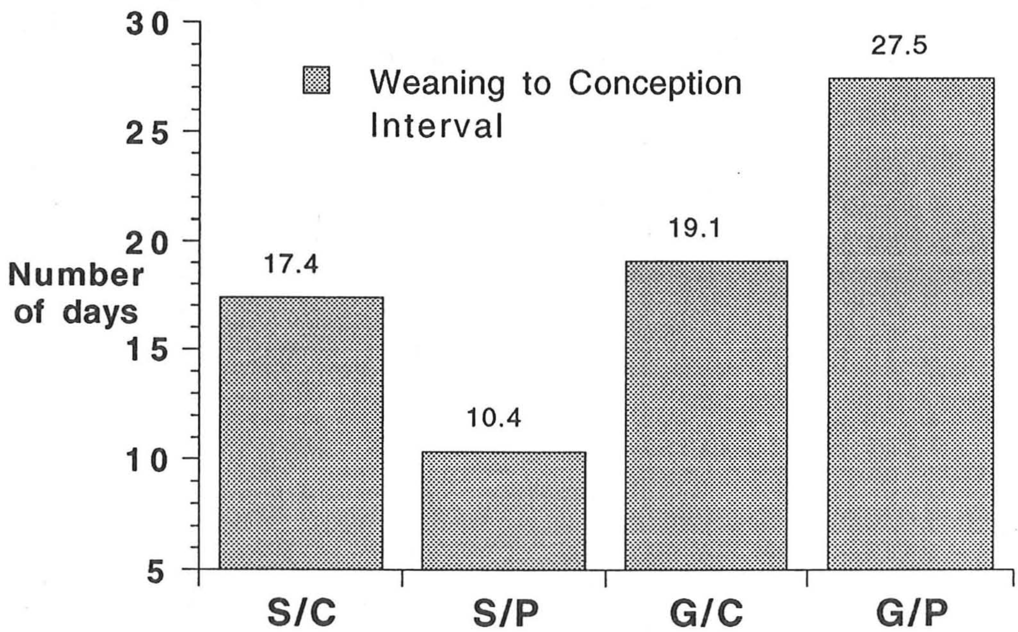


Figure 6.6 Mean weaning to conception interval (days) for sows in the four Treatments.

6.3.2 Behaviour results

There were a large number of significant differences in behaviour between dry sow systems, farrowing systems and Treatments, both in terms of number of posture changes, and total duration of each behaviour category. The results are presented in terms of comparison by dry sow system, by farrowing system and by Treatment, in tabular form showing each Period separately. For comparison by Treatment, they are also presented in graphical form showing all three Periods together. The Periods studied are described in Section 6.2.

Stall-housed sows stood more often and for longer than group-housed sows during the first 24 hour period in the farrowing conditions (see Table 6.1). They also lay sternally more often and spent less time lying with the udder exposed. Stall sows tended to change posture more than group sows during the Entry Period. During 72-48h Prepartum, stall sows again stood for longer and spent less time lying with the udder exposed. They also sat less frequently than group sows. During 24-0h Prepartum, group sows stood, sat and lay sternally more often than stall sows. Thus, the total number of posture changes during this period was larger for group sows. Group sows also spent longer sitting, but there were no differences in duration for the other posture types.

Table 6.1 Mean number of posture changes and total duration spent in each posture for sows from stalls or groups, during each Period in the farrowing house.

Behaviour	*Nº of Changes* Stalls	Group	p-Value	*Total Duration* Stalls	Group	p-Value
Stand 1	17.5 [a]	12.8 [b]	0.013	183.2 [a]	112.1 [b]	0.001
Sit 1	15.1	15.4	0.858	43.9	48.3	0.552
Sternal Lie 1	28.0 [a]	23.7 [b]	0.010	450.9	390.8	0.173
Lateral Lie 1	7.0	7.1	0.905	760.7 [a]	888.8 [b]	0.009
Total 1	67.7	59.6	0.088	-	-	-
Stand 2	13.8	14.2	0.788	198.7 [a]	89.7 [b]	0.001
Sit 2	12.2 [a]	15.9 [b]	0.031	40.6	47.5	0.336
Sternal Lie 2	26.0	25.0	0.608	423.6	421.8	0.962
Lateral Lie 2	7.6	7.7	0.960	773.5 [a]	879.5 [b]	0.040
Total 2	59.6	62.8	0.520	-	-	-
Stand 3	35.7 [a]	51.3 [b]	0.001	363.6	339.5	0.399
Sit 3	27.2 [a]	43.1 [b]	0.001	117.1 [a]	171.4 [b]	0.009
Sternal Lie 3	48.6 [a]	65.4 [b]	0.001	647.2	595.9	0.144
Lateral Lie 3	15.1	16.5	0.329	325.1	332.5	0.829
Total 3	126.6 [a]	176.3 [b]	0.001	-	-	-

[a,b] Values without common superscript in same row are significantly different at p<0.05.

Comparing the results by farrowing system (see Table 6.2), crated sows lay on their udder more often and for longer than penned sows during the Entry Period. Crated sows also lay with their udder exposed more often in this period, but there was a tendency for this posture to be of shorter duration than penned sows. The total number of posture changes during the Entry Period was greater for sows introduced into crates. During 72-48h Prepartum, crated sows stood, lay on their udder and lay with their udder exposed more often than penned sows, and thus, the total number of posture changes was greater. Again, crated sows spent more time lying on their udder and tended to spend less time lying with their udder exposed, than penned sows.

During 24-0h Prepartum, crated sows stood, sat, lay on their udder and lay with their udder exposed more often than penned sows. Therefore, the total number of posture changes during this period, was far greater for crated sows. During this period, crated sows stood for longer, whereas penned sows lay on their udders for longer.

Table 6.2 Mean number of posture changes and total duration spent in each posture for all sows in farrowing crates or pens, during each Period.

	Nº of Times			*Total Duration*		
Behaviour	**Crates**	**Pen**	**p-Value**	**Crates**	**Pen**	**p-Value**
Stand 1	16.5	13.8	0.179	141.3	153.9	0..477
Sit 1	16.4	14.1	0.130	44.5	47.7	0.665
Sternal Lie 1	27.8 a	23.9 b	0.022	474.8 a	366.9 b	0.012
Lateral Lie 1	8.3 a	5.8 b	0.025	779.5	870.1	0.069
Total 1	69.3 a	58.1 b	0.015	-	-	-
Stand 2	15.4 a	12.5 b	0.041	137.5	131.6	0.845
Sit 2	15.4	13.5	0.281	43.1	46.2	0.662
Sternal Lie 2	27.4 a	23.5 b	0.037	465.2 a	379.8 b	0.015
Lateral Lie 2	9.5 a	5.8 b	0.001	792.6	879.2	0.092
Total 2	67.8 a	55.3 b	0.007	-	-	-
Stand 3	50.6 a	36.3 b	0.001	386.8 a	316.2 b	0.011
Sit 3	41.7 a	28.6 b	0.004	149.8	138.7	0.609
Sternal Lie 3	66.3 a	47.7 b	0.001	574.3 a	668.8 b	0.005
Lateral Lie 3	18.1 a	13.5 b	0.001	341.3	316.3	0.462
Total 3	176.8 a	126.1 b	0.001	-	-	-

a,b Values without common superscript in same row are significantly different at $p<0.05$.

The above results clearly demonstrate differences in behavioural response between sows from different dry sow systems, and also between sows in different farrowing conditions. In the following section, the results are compared by Treatment, in order to gauge to what degree the previous experience of the dry sow system has, on the behavioural responses to farrowing conditions.

In the Entry Period, stall sows in farrowing crates stood more often than group sows in crates and group sows in pens (see Table 6.3). Group sows in farrowing pens lay on their udders less often than stall sows in crates and stall sows in pens. In total, stall sows in crates changed posture more often than group sows in pens.

Table 6.3 Mean number of posture changes for each behaviour category during the Entry Period, for sows in the four Treatments.

Behaviour	S/C	S/P	G/C	G/P	p-Value
Stand	19.27 ^{b}	15.82 ^{ab}	13.73 ^{a}	11.91 ^{a}	0.0415
Sit	15.91	14.36	16.91	15.91	0.4748
Lie on Udder	29.91 ^{a}	26.09 ^{a}	25.64 ^{ab}	21.73 ^{b}	0.0058
Lie Udder Exposed	8.18	5.82	8.46	5.82	0.1754
Total Number	73.3 ^{a}	62.1 ^{ab}	65.3 ^{ab}	54.0 ^{b}	0.0292

^{a,b} Values without common superscript in same row are significantly different at p<0.05.

Stall sows, both in crates and pens, spent longer standing than group sows in both farrowing systems, and spent less time lying with udder exposed than group sows in pens (see Table 6.4). Stall-housed sows in farrowing crates also spent longer lying on their udder than stall-housed sows in pens and group-housed sows in pens.

Table 6.4 Mean total duration (minutes) of each behaviour category during the Entry Period, for sows in the four Treatments.

Behaviour	S/C	S/P	G/C	G/P	p-Value
Stand	168.8 ^{a}	197.7 ^{a}	113.9 ^{b}	110.2 ^{b}	0.0001
Sit	36.67	51.16	52.35	44.25	0.4071
Lie on Udder	512.2 ^{a}	389.6 ^{b}	437.4 ^{ab}	344.2 ^{b}	0.0382
Lie Udder Exposed	722.6 ^{a}	798.9 ^{a}	836.4 ^{ab}	941.2 ^{b}	0.0137

^{a,b} Values without common superscript in same row are significantly different at p<0.05.

During 72-48h Prepartum, stall sows in farrowing crates and pens sat less often than group sows in farrowing crates (see Table 6.5). Group sows and stall sows in farrowing crates lay with udder exposed more often than group sows in farrowing pens. Group sows in farrowing crates also lay with udder exposed more often than stall sows in farrowing pens. In total, group sows in farrowing crates changed posture more often than stall and group sows in farrowing pens.

Table 6.5 Mean number of posture changes for each behaviour category during 72-48h Prepartum, for sows in the four Treatments.

Behaviour	S/C	S/P	G/C	G/P	p-Value
Stand	14.86	12.71	16.00	12.40	0.2247
Sit	12.43 ^{a}	12.00 ^{a}	17.40 ^{b}	14.50 ^{ab}	0.0937
Lie on Udder	27.70	24.29	27.10	27.71	0.2070
Lie Udder Exposed	9.00 ^{ac}	6.29 ^{bc}	9.90 ^{a}	5.50 ^{b}	0.0036
Total Number	64.0 ^{ab}	55.3 ^{a}	70.4 ^{b}	55.3 ^{a}	0.0472

^{a,b,c} Values without common superscript in same row are significantly different at $p<0.05$.

Again, stall sows in farrowing crates and pens spent longer standing than group sows in farrowing crates and pens (see Table 6.6). Stall sows in crates spent less time lying with udder exposed than group sows in pens.

Table 6.6 Mean total duration (minutes) of each behaviour category in 72-48h Prepartum, for sows in the four Treatments.

Behaviour	S/C	S/P	G/C	G/P	p-Value
Stand	202.1 ^{a}	195.2 ^{a}	92.2 ^{b}	87.1 ^{b}	0.0011
Sit	31.7	49.5	51.1	43.9	0.2361
Lie on Udder	467.3	379.9	463.8	379.8	0.1271
Lie Udder Exposed	739.4 ^{a}	807.7 ^{ab}	829.8 ^{ab}	929.7 ^{b}	0.0623

^{a,b} Values without common superscript in same row are significantly different at $p<0.05$.

During 24-0h Prepartum, there was a large increase in the total number of posture changes across all four Treatments, but especially for group-housed sows in farrowing crates. These sows stood, sat and lay on their udder more often than sows in the other three Treatments (see Table 6.7). They also lay with udder exposed more often than group sows and stall sows in farrowing pens. Stall sows in pens stood less often than group sows in pens and lay on their udder less often than stall sows in crates. In total, group sows in farrowing crates changed posture far more often than group sows in farrowing pens and also stall sows in farrowing crates and pens. Stall sows in pens changed posture less often than the other three Treatments.

Table 6.7 Mean number of posture changes for each behaviour category during 24-0h Prepartum, for sows in the four Treatments.

Behaviour	S/C	S/P	G/C	G/P	p-Value
Stand	38.82 ^{ab}	32.55 ^{a}	62.46 ^{c}	40.09 ^{b}	0.0001
Sit	29.09 ^{a}	25.36 ^{a}	54.36 ^{b}	31.91 ^{a}	0.0001
Lie on Udder	54.09 ^{b}	43.00 ^{c}	78.46 ^{a}	52.36 ^{bc}	0.0001
Lie Udder Exposed	16.82 ^{ab}	13.73 ^{b}	19.82 ^{a}	13.18 ^{b}	0.0015
Total Number	138.5 ^{b}	114.6 ^{c}	215.1 ^{a}	137.5 ^{b}	0.0001

^{a,b,c} Values without common superscript in same row are significantly different at $p<0.05$.

Coupled with this large increase in number of posture changes for all Treatments, was an increase in the length of time spent standing, sitting and lying on the udder (see Table 6.8). Stall sows and group sows in farrowing crates spent longer standing than group sows in pens. Group sows in crates also spent less time lying on the udder than penned sows, and longer sitting than stall sows.

Table 6.8 Mean total duration (minutes) of each behaviour category during 24-0h Prepartum, for sows in the four Treatments.

Behaviour	S/C	S/P	G/C	G/P	p-Value
Stand	395.4 ^{a}	331.7 ^{ab}	378.2 ^{a}	300.7 ^{b}	0.0642
Sit	111.6 ^{a}	122.6 ^{a}	188.0 ^{b}	154.9 ^{ab}	0.0415
Lie on Udder	610.2 ^{ab}	684.1 ^{a}	538.4 ^{b}	653.4 ^{a}	0.0147
Lie Udder Exposed	348.7	301.6	333.9	331.0	0.8023

^{a,b} Values without common superscript in same row are significantly different at $p<0.05$.

The total number of posture changes per Period are shown graphically in Figure 6.7. During the Entry Period and 72-48h Prepartum, there are some significant differences between Treatments which have been referred to earlier, but these differences are not particularly large compared to the differences seen during 24-0h Prepartum. All Treatments show a large increase in the number of posture changes during 24-0h Prepartum. Group-housed sows farrowing in crates show the largest increase and change posture significantly more often than the other three Treatments during 24-0h Prepartum. Stall-housed sows farrowing in pens changed posture significantly less often than the other three Treatments during this period.

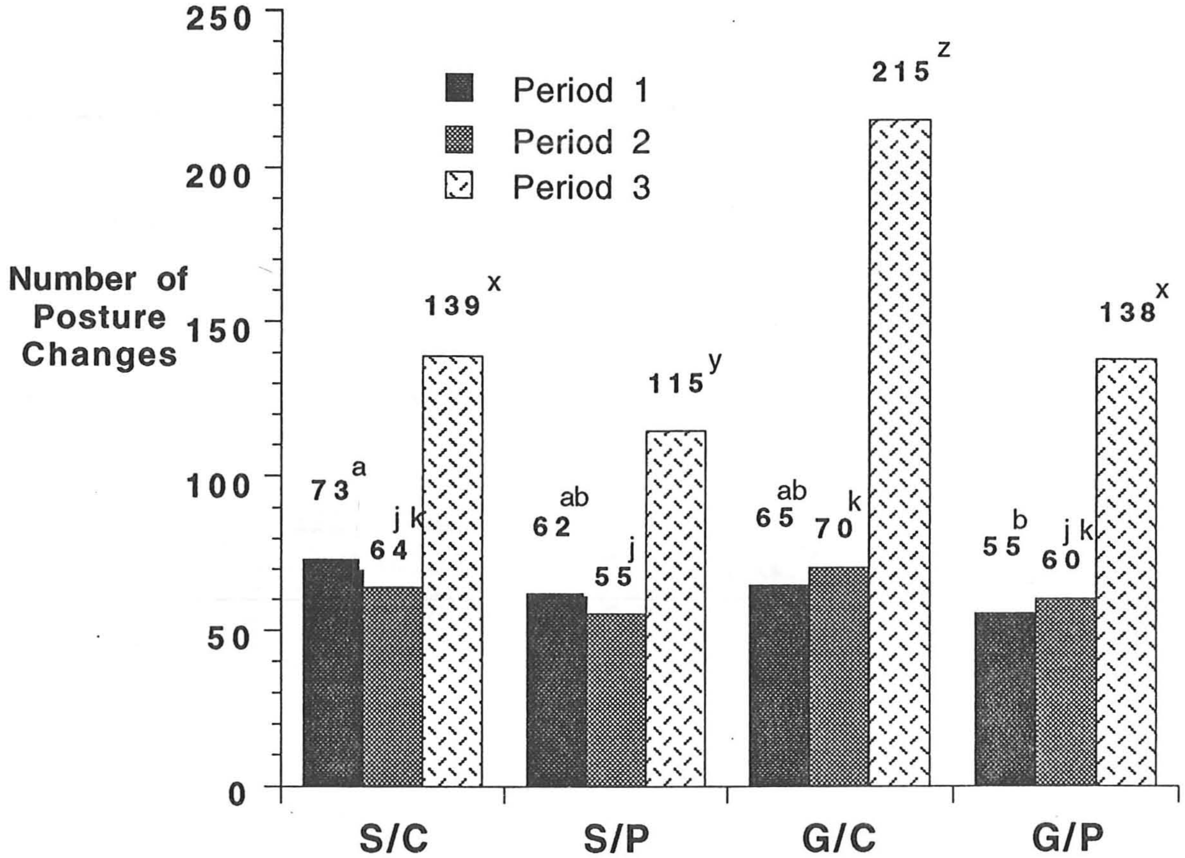


Figure 6.7 Mean total number of posture changes during each period, for sows in the four Treatments. a,b & j,k & x,y,z Values without a common superscript are significantly different at $p<0.05$.

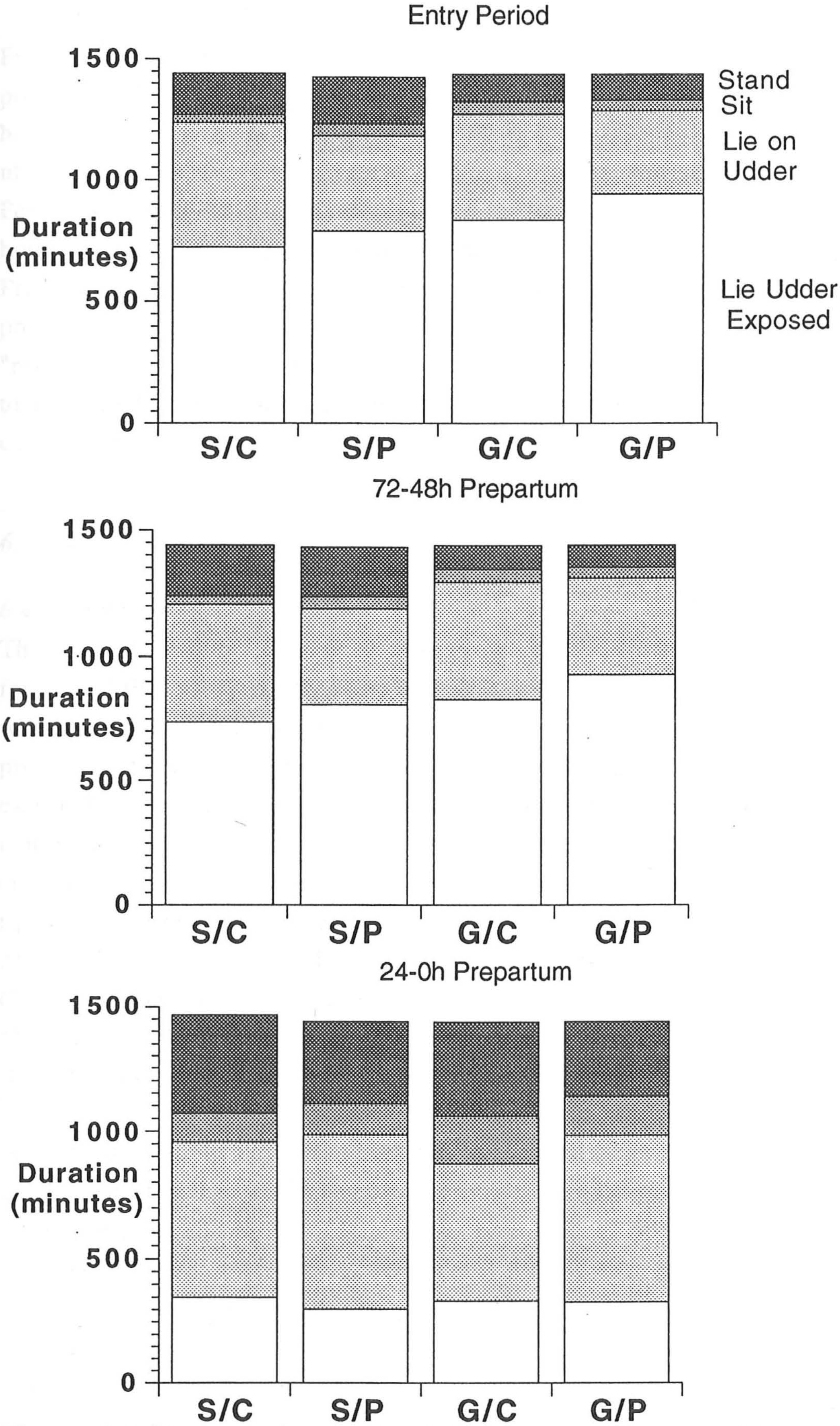


Figure 6.8 Stack graphs showing total amount of time spent in each posture during all three Periods, for sows in the four Treatments.

Figure 6.8 shows the total amount of time that sows from all four Treatments spent in each posture per Period. During the Entry Period and 72-48h Prepartum, the majority of the 24 hours was spent lying with udder exposed, i.e. in a "restful" posture. This ranged from a minimum of 50.18% of 24 hours for stall-housed sows in farrowing crates during the Entry Period, through S/P and G/C Treatments to a maximum of 65.36% of 24 hours for group-housed sows in farrowing pens during the Entry Period. The time budgets during 72-48h Prepartum were very similar to the Entry Period. However, in the 24 hours immediately preceding farrowing, the sows became increasingly agitated, and the time spent in the "restful" posture of lying laterally with udder exposed diminished to about 20-25% of the total period. Correspondingly, the amount of time spent in all three other "restless" posture categories increased.

6.4 Discussion

6.4.1 Production

The sows used in this study were all between third and sixth parity, with the majority being fourth and fifth parity and therefore at their peak in terms of production. This, together with the small sample numbers, meant that there were no significant differences in production figures between Treatments, although there were a number of tendencies especially when either dry sow system or farrowing system results were combined. Stall-housed sows did tend to have larger litters. The reasons for this are dictated by the dry sow environment and have been covered in detail in Chapter 5 when discussing the whole herd figures. There was also a tendency for sows farrowing in crates to have more piglets born dead. This is in agreement with findings reported by Bäckström (1973) and Gustafsson (1982), and may be attributed to a lack of exercise resulting in increased parturition time and increased likelihood of neonatal death due to anoxia and incidence of dystocia (Sprecher et al, 1975, Sommer et al, 1982, Cronin & Simpson, in press).

In terms of mortality rates, these tended to be higher in farrowing pens than in farrowing crates, and tended to be higher for stall-housed sows than group-housed sows. The difference between farrowing systems has been reported in a number of studies (e.g. Glastonbury, 1976, Aherne, 1982, Collins et al, 1987, Cronin & Smith, 1992). In relation to the effects of dry sow systems on farrowing, Hansen & Vestergaard (1984) and Cronin & Simpson (in press) have both noted higher mortality in Treatments which changed from a confined system to an open system or *vice versa*. In this study, sows moving from stalls to pens did have the highest mortality, in agreement with these findings, but sows moving from the group to crates had the lowest mortality rates.

The mortality rates also agree with results reported by Gravås (1982) who noted no difference in mortality between sows moving from stalls to crates and sows moving from loose housing to open pens. The slightly higher mortality figures for stall-housed sows may be partially explained by the average piglet weight at birth. Stall-housed sows gave birth to lighter piglets and bigger litters. This may increase the likelihood of some piglets being born near the critical 1kg weight, which may predispose them to overlaying. This does not agree with results obtained by Den Hartog (1993) who reported stall-housed sows as giving birth to heavier piglets than group-housed sows.

There was a tendency for group-housed sows in pens to have a longer weaning to conception interval than stall-housed sows in crates and pens. Again, this difference is explainable in terms of the subsequent dry sow housing system, which has been discussed in Chapter 5.

6.4.2 Behaviour

The results for the Entry Period demonstrate that all sows appeared to settle fairly well into their farrowing conditions. Table 6.2 does show that sows moved into crates changed posture more often than sows moved into pens (69.3 vs. 58.1), which may highlight some initial unease in this farrowing system. These crated sows also lay on their udder more often and for longer than penned sows during the Entry Period and 72-48h Prepartum, and tended to lay with their udders exposed less, which may demonstrate an inability to obtain a comfortable body position.

Table 6.1 also illustrates differences in response to the farrowing conditions, between sows from different dry sow systems. Previously stall-housed sows stood more often (17.5 times) and for longer (183.2 minutes) than group-housed sows (12.8 times and 112.1 minutes). These differences in standing for stall-housed sows can probably be explained in terms of increased levels of rooting behaviour. In their dry sow environment, they are housed only on concrete. In the farrowing house, they have access to either wood-shavings or straw, and consequently, spend a great deal of time rooting and chewing. Thus, this may be seen as a 'rebound' behaviour - i.e. they spend time rooting simply because they now have the opportunity. The amount of time spent standing appeared to be at the expense of the amount of time spent lying with the udder exposed, i.e. the amount of time spent sleeping. Stall sows spent significantly less time in this posture (760.7 minutes) than group sows (888.8 minutes). These results are repeated during 72-48h Prepartum, with stall sows again spending more time standing (198.7 minutes vs. 89.7 minutes) and less time lying with the udder exposed (773.5 minutes vs. 879.5 minutes). This shows a consistency of behavioural adaptation to a new environment rather than a transient response.

When the Entry Period is looked at in terms of Treatment, we see that many of the differences between stall sows and group sows, and between crated and penned sows, are due to the Stall/Crate Treatment. These sows are the most active within the Entry Period, in terms of total number of posture changes, and spent the most time lying on their udder and least time lying with udder exposed. In many respects, these sows are undergoing the least change in terms of housing environment, going from confinement to confinement and effectively single housing to single housing, whereas the other three Treatments involve a change in at least one of these factors. Thus, it may be the case that there is little alteration of this Treatment daily behaviour patterns, except for the amount of time spent standing and carrying out rooting of substrate as noted above. This longer time spent standing by stall sows introduced into crates has also been noted by Pierce et al (1993), in a study looking at the short-term adaptation to farrowing crates.

When housed in the stalls, the restrictive environment does make it difficult for the sows to lie laterally, and thus it would be expected that stall sows housed in crates would spend the least time lying with udder exposed, as is seen during the Entry Period and 72-48h Prepartum, and the most time lying on the udder, as seen during the Entry Period (and during 72-48h Prepartum but not significantly). It would also be expected that group sows in farrowing pens would change posture least often, spend the most time lying with udder exposed and the least time lying on the udder. This is indeed seen in both the Entry Period and 72-48h Prepartum. Thus, the two Treatments with the least environmental change, do react the expected way during the Entry Period and 72-48h Prepartum.

The Treatments involving change from a confined to an open environment and *vice versa*, exhibit some expected behavioural patterns, but also some unexpected ones. It may be expected that during the Entry Period, behavioural disturbance would be greatest for those sows changing between confined and open systems. However, this does not appear to be the case. In terms of total number of posture changes, sows in the S/P and G/C Treatments are intermediate between sows in the S/C and G/P Treatments, whereas it may have been expected that group sows moved into farrowing crates would have been the most disturbed. In terms of behavioural time budget (see Figure 6.8), the results are more in line with expectations. The sows in the G/C Treatment tends to shift from spending time lying with udder exposed to lying on the udder, compared with those in the G/P Treatment. Also, the S/P Treatment sows shift the other way, from spending time lying on the udder to lying with udder exposed compared with the S/C Treatment sows. These shifts can be equated with the comparative ease of lying within the two farrowing systems.

During 72-48h Prepartum, the G/C Treatment sows were the most active in terms of total number of posture changes. This, and the fact that these sows sat the most often, which in itself is indicative of unease, perhaps highlights an increasing disturbance of normal behaviour. However, in terms of behavioural time budget, there is little difference between the 72-48h Prepartum and the Entry Period (see Figure 6.8), with similar amounts of time spent in the two lying postures, in each Period.

As farrowing approached, there was a very large increase in activity (see Figure 6.7), with all Treatments showing a significant increase in posture changes during the last 24 hours immediately prior to farrowing ($p<0.001$). Group sows changed posture significantly more than stall sows (see Table 6.1), and crated sows significantly more than penned sows (see Table 6.2). Crated sows also stood for longer, and spent longer lying on their udder, which demonstrates increased discomfort over penned sows. Thus, all sows, independent of dry sow and farrowing sow accommodation type, show an upsurge in nest-building style behaviour, in this last 24 hours prior to parturition, which agrees with a number of studies (Vestergaard & Hansen, 1984, Lammers & de Lange, 1986, Widowski & Curtis, 1990). However, the extent and nature of behaviour shown is dependent on accommodation type.

The motivation for nest-building is very strong, and has been well-documented (Jensen, 1989, Zanella & Zanella, 1993), even when sows are presented with pre-constructed nests (Arey et al, 1991). However, in farrowing systems that restrict freedom of movement, nest-building cannot be carried out, and this inability manifests itself in the modification of behaviour, namely an increase in postural changes. Hansen & Curtis (1981) demonstrated results similar to this study. Sows housed in farrowing crates stood or sat up more often than sows housed in farrowing pens, during the last 48 hours prior to parturition. The same was found with gilts housed in crates, pens or "turn-around" crates (Heckt et al, 1988). Reinforcing this greater behavioural disturbance for crated sows, is a study by Lawrence et al (1993) which reports a greater increase in cortisol concentrations as parturition nears, for gilts in crates compared with gilts in pens.

However, these studies do not take the preceding dry sow system into account. When comparisons are made by Treatment, this increase in the total number of posture changes was most marked in the group-housed sows farrowing in crates, with a corresponding decrease in average duration of posture for these sows. They stood, sat and lay significantly more often than the other three Treatments, and spent longer sitting. These results would appear to highlight an increased amount of frustrated maternal behaviour near the time of farrowing for confined sows that have previously gestated in an open environment, a result reported by Vestergaard & Hansen (1984).

Conversely, the stall sows farrowing in pens stood least often, and changed posture in total, significantly less than the other three Treatments. The fact that stalls sows in general, changed posture less frequently than group sows. This may not be due to decreased maternal motivation for these sows, but more to effort of movement. Stall sows have no opportunity for exercise and may therefore have decreased muscular "fitness". This may make posture changes difficult to carry out, and therefore these sows will be less motivated to carry out unnecessary movements.

CHAPTER 7

The effects of behaviour on heart rate responses of stall-housed and group-housed Sows

7.1 Introduction

Heart rate has been acknowledged as a useful indicator of an animal's internal physiological state (Fraser & Broom, 1990) and has been widely used in studies on a number of species. The relationship between heart rate and behaviour has been demonstrated in humans (Smith & Kampine, 1980), sheep (Baldock et al, 1988) and chicks (Potter, 1987), where heart rate has been seen to differ according to posture and locomotion with modification by specified activities. Specific responses to feeding have been reported in calves, lambs, kids, dogs (all Bloom et al, 1975), cats (Matsukawa & Ninomija, 1987) and pigs (Schouten et al, 1991), with all species showing a rise in heart rate when feeding occurs. Schouten et al (1991) also demonstrated a difference in response between confined and non-confined sows.

In the past, studies of heart rate have involved various methods of data collection, such as implanted blood pressure transducers (Bloom et al, 1975), ECG (Gregory & Wotton, 1981) and FM telemetry (Schouten et al, 1991). Each method has advantages and disadvantages as regards degree of invasive technique, ease of data collection and handling and cost. Recent increase in the use of applied physiology in training regimes of human athletes, has led to an improved technology of heart rate monitors, making the measurement of heart rates painless and easy to record.

The objectives of these studies were to determine the applicability of an unmodified human heart rate monitor for use on pigs and furthermore to investigate the relationship between heart rate and behaviour in sows housed in three different dry sow housing conditions and in farrowing crates.

7.2 Study One

The effect of stage of gestation on basal heart rate of group-housed sows

7.2.1 Introduction

Baldock et al (1988) have identified a number of factors that affect heart rate in sheep, such as behaviour, individual identity and season. These factors have also been reported in red deer (Price et al, 1993). Whereas the first two factors are applicable to pigs, the effects of season may be questionable. Sheep are exposed to the seasonal extremes of temperature and daylength etc. and are seasonally polyœstrous, being limited to a single gestation of 142-150 days, per year. Thus, season is closely tied to stage of gestation. Pigs are polyœstrous all year round, with a gestation length of 114 days, and apart from three to four weeks of lactation plus a variable weaning to conception interval of two or so weeks, spend most of the year at some stage of pregnancy. Also, the majority of breeding sows are housed indoors, and are protected from environmental extremes. Therefore, rather than a seasonal effect on heart rate, there is more likely to be an effect due to stage of gestation.

The aim of this experiment was to determine the effect that stage of gestation has on the basal heart rate of sows within the large group house.

7.2.2 Methods

Six Large White X Landrace sows of similar age and parity were monitored using a Polar Sportester. Each sow was monitored on five occasions (days i - v) at intervals of approximately twenty days during the months of April, May and June. Heart rate was measured continuously between 0900 hrs and 1200 hrs, the period during which sows were at their most inactive. The sows were subjected to continuous direct observation during the whole monitoring period. From the behavioural data, the periods of lying laterally with eyes closed, which equated to basal heart rate, were marked on the resulting heart rate graphs.

The heart rate graphs were examined to find continuous periods of minimum heart rate, and the corresponding numerical data were analysed to give an average basal heart rate over 10 minutes.

7.2.3 Results

Individually, the sows showed an increasing basal heart rate as gestation progressed towards full term (see Table 7.1). Also, the rate of increase generally became greater as pregnancy progressed.

Table 7.1 Basal heart rate (beats per minute) and stage of gestation (days after service) for individual sows on five separate days.

Sow Nº	Day (i)	Basal HR	Day (ii)	Basal HR	Day (iii)	Basal HR	Day (iv)	Basal HR	Day (v)	Basal HR
27	11	54.3	44	57.2	72	72.5	88	76.6	109	78.0
110	5	52.5	43	53.8	63	58.2	87	67.4	97	71.7
112	13	44.6	36	40.3	58	45.4	93	50.7	99	54.0
141	26	48.7	51	43.5	68	50.4	86	59.9	113	68.7
162	22	50.0	45	55.4	66	56.4	73	59.6	92	66.8
208	30	48.7	56	55.1	70	60.4	89	66.6	99	70.4

When stage of gestation and basal heart rate were correlated for individual sows, the best fit was obtained using second order polynomial regression. For three sows, the line of best fit was significant and for the other three, the line of best fit tended towards significance (see Table 7.2).

Table 7.2 Polynomial regression equations of the relationship between basal heart rates (beats per minute) and stage of gestation (days after service) for individual sows.

Sow Number	Equation	r-Value	p-Value
27	$y = 49.651 + 0.279x - 6.56E^{-6}x^2$	0.956	0.0852
110	$y = 53.006 - 0.121x + 0.003x^2$	1.000	0.0005
112	$y = 46.224 - 0.214x + 0.003x^2$	0.963	0.0730
141	$y = 52.417 - 0.311x + 0.004x^2$	0.959	0.0801
162	$y = 50.080 - 0.022x + 0.002x^2$	0.976	0.0470
208	$y = 42.505 + 0.169x + 0.001x^2$	0.999	0.0014

From the equations, predicted minimum and maximum basal heart rate values were calculated (see Table 7.3), to determine whether there was any relationship between basal heart rate change over gestation and litter size. There was no correlation between change in basal heart rate over gestation and number of piglets born.

Table 7.3 Minimum and maximum basal heart rate values (beats per minute) predicted from the correlation equations generated for individual sows.

Sow Number	Minimum	Maximum	Change	Litter Size
27	49.7	81.4	31.8	9
110	53.0	78.2	25.2	9
112	46.2	60.8	14.6	12
141	52.4	68.9	16.5	12
162	50.1	73.6	23.5	14
208	42.5	74.8	32.3	14

When all data points are included, and correlation between basal heart rate and stage of gestation carried out, the line of best fit is again second order polynomial (see Figure 7.1).

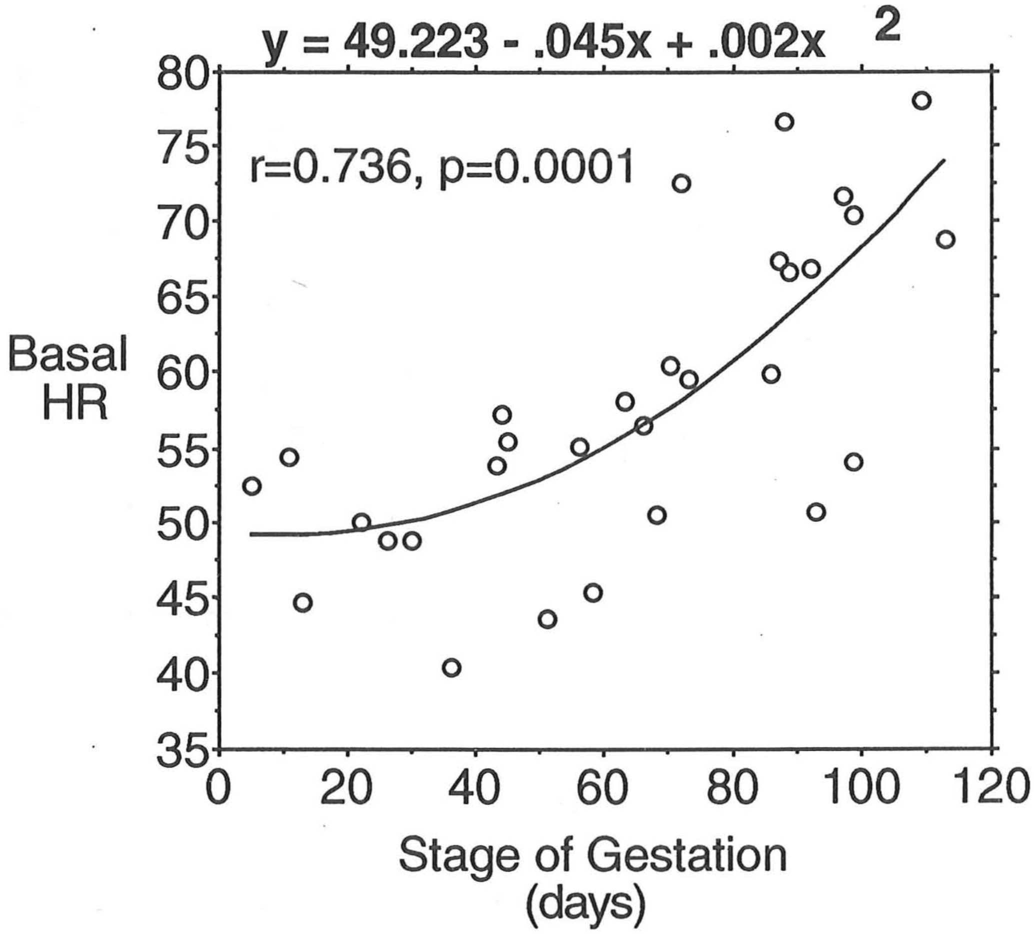
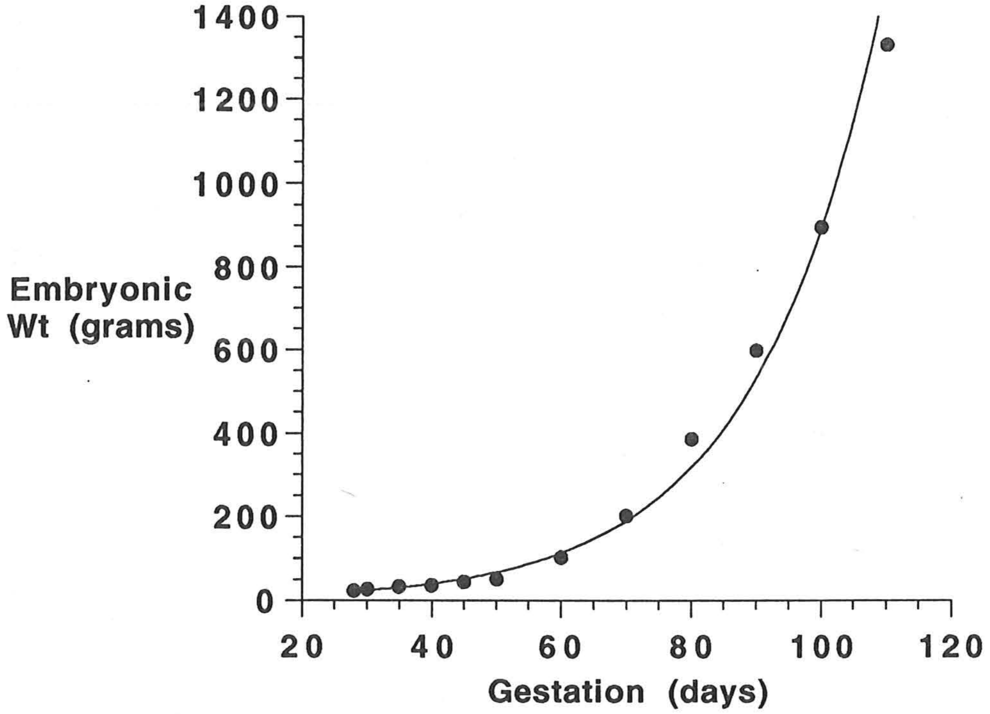


Figure 7.1 Graph showing correlation between basal heart rate and stage of gestation.

7.2.4 Discussion

The results from Table 7.1, indicate that basal heart rate increases as gestation progresses for all sows, but the amount of increase depends on the individual identity (see Table 7.3). The results also demonstrate that the rise is not constant (see Table 7.2 and Figure 7.1), but rather that the rate of increase grows towards the last third of gestation. This is expected, because the first third of gestation is taken up by embryonic cellular differentiation, and it is during the last third of pregnancy that the fœtuses growth rate is maximal (see Figure 7.2), and hence demand for uterine blood flow, is maximal.



After: Marrable (1971)

Figure 7.2 Graph showing embryonic weight increase during gestation, in the sow.

The results clearly demonstrate that basal heart rate is affected by stage of gestation. Thus, for the following experiments to be valid, it is very important to match experimental treatments for stage of gestation. Any bias towards early or late gestation will have a major influence on results, both in terms of absolute values obtained, and also in their interpretation.

7.3 Study Two

Differences in heart rate during specified behaviours between stall-housed and group-housed sows

7.3.1 Introduction

The effect of behaviour on heart rate has been demonstrated in humans (Smith & Kampine, 1980), sheep (Baldock et al, 1988), red deer (Price et al, 1993) and chicks (Potter, 1987). Any effect may be due to a physical component, such as posture or locomotion, together with modification by a physiological component in response to various stimuli, such as handling, transport, feeding or social interaction. Physiological responses to feeding have been well-documented in a number of species and in pigs, feeding has resulted in rises in heart rate (Schouten et al, 1991) and also blood pressure (Houpt et al, 1983). Schouten et al (1991) have also demonstrated differences in heart rate response at feeding between loose-housed and tethered sows.

The aims of this experiment were to determine the effects of specified behaviours such as feeding, drinking, rooting and lying, on heart rate and to investigate any differences in heart rate response between the three dry sow housing systems.

I acknowledge the assistance of Andrew Rudd during this experiment.

7.3.2 Methods

All work was carried out at the Animal Welfare Group's pig unit during September and October. The sows used in the study were all Large White X Landrace sows of similar age (mean parity = 7.52 ± 1.09) and similar stage of pregnancy (57.76 days ± 22.34). Housing was comprised of three adjacent buildings of identical design externally, but each modified internally to accommodate one of the following systems: 1) Large group of 25-30 with an Electronic Sow Feeder system, 2) Small Groups of 5 with individual feeders, 3) Permanent Individual stalls. These systems have been described in detail in Chapter 4. Figure 7.3 shows the spatial relationship between these systems.

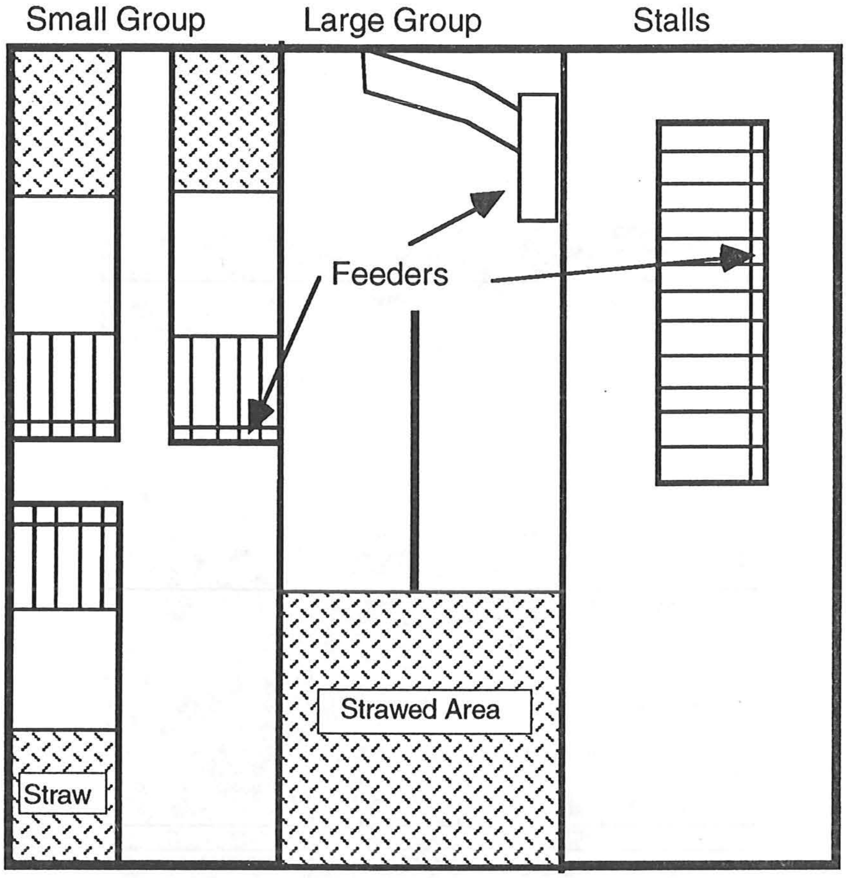


Figure 7.3 Diagram showing the spatial relationship between the three dry sow systems.

Sows in the stalls and small groups (see Plates 7.1 & 7.2) were fed simultaneously and manually at 0700 hrs as part of the usual daily routine, by the usual stockmen. The sows were fed between 2-3kg depending on stage of pregnancy, in a single delivery. Sows housed in the ESF system (see Plate 7.3) were fed a computer-controlled amount of between 2-3kg in 200g pulses. The full day's allocation was invariably eaten in a single visit. The computer ran on a 24-hour cycle and switched over daily at 1500hrs.

The heart rates of 21 sows, 7 from each system, were monitored between 30 minutes pre-feeding and 90 minutes post-feeding. Constant direct observation of behaviour was carried out simultaneously throughout this period and the exact feeding periods recorded. Behaviours which were recorded were feeding, drinking, rooting and lying with eyes open, as these were performed regularly by all sows monitored in all three systems. Basal heart rate levels were also recorded, approximately 12-15 hours after feeding had occurred. Basal heart rate was assessed when the animals were lying with their eyes closed.

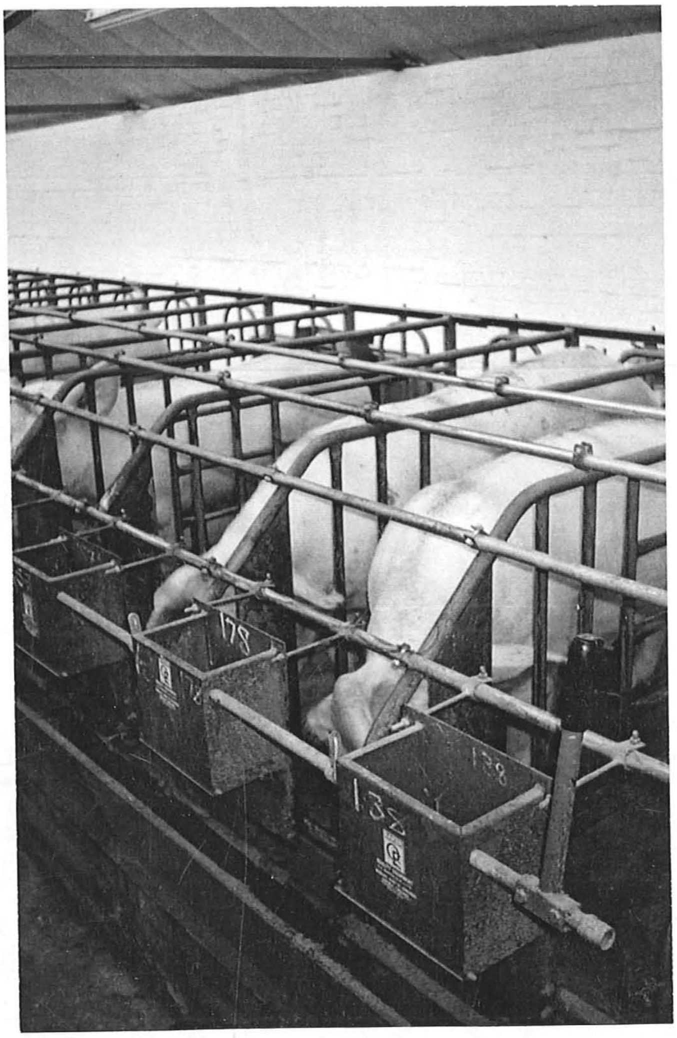


Plate 7.1 The stall house, showing the manually operated feeding system.

Plate 7.2 The group house showing the individual feeders.

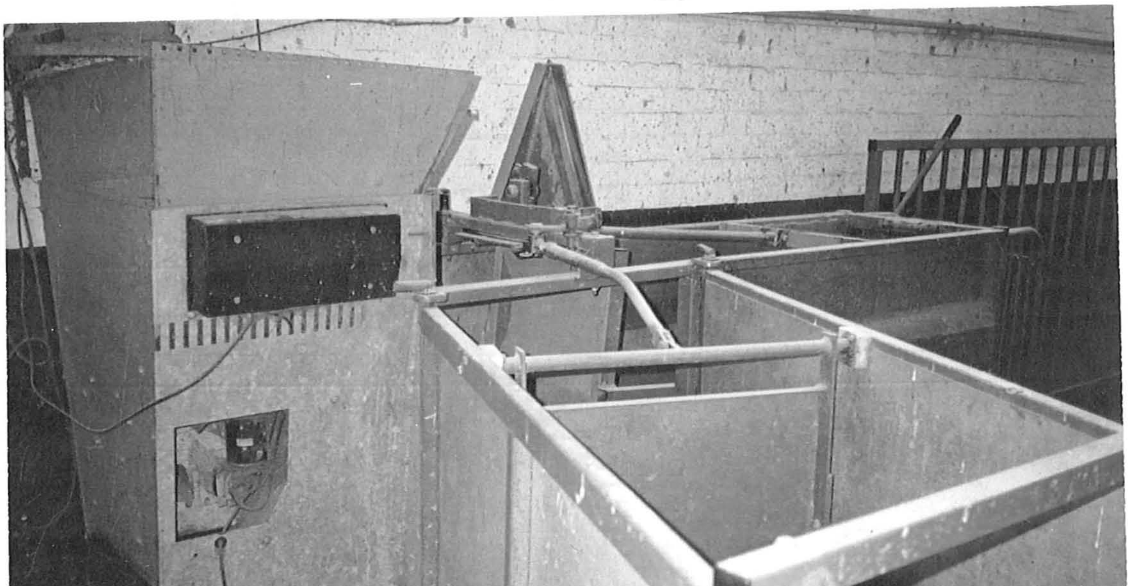


Plate 7.3 The Electronic Sow Feeder.

The graphical results from the heart rate monitors were compared with the behavioural data, and marked for when periods of the specified behaviours were being carried out. All animals were recorded four times for each behaviour category and the results averaged. The corresponding numerical data were then analysed and heart rate during different behaviours was compared, first within each system and then between systems, using Analysis of Variance. For feeding, two values were determined. These were; 1) an absolute peak value - the highest heart rate recorded during feeding, and 2) an average value - heart rate averaged over the first 5 minutes of feeding.

7.3.3 Results

The type of behaviour being carried out had a significant effect on the heart rate of sows within each system (see Table 7.4). For all three systems, heart rate was highest during feeding and lowest during lying, with rooting and drinking intermediate.

Table 7.4 Mean heart rate response (in beats per minute) to specified behaviours, compared within each System.

	Behaviour					
System	Basal	Feeding	Rooting	Drinking	Lying	p-Value
Stalls	53.8 ^{a}	117.9 ^{b}	94.0 ^{c}	100.7 ^{c}	65.7 ^{d}	0.0001
Large Group	46.7 ^{a}	105.9 ^{b}	81.2 ^{c}	87.8 ^{c}	57.9 ^{d}	0.0001
Small Group	45.9 ^{a}	102.5 ^{b}	87.7 ^{c}	96.9 ^{b}	59.2 ^{d}	0.0001

^{a,b,c,d,e} Values without common superscript in same row are significantly different at $p<0.05$.

When comparing between systems (see Table 7.5), stall-housed sows had significantly higher basal heart rates (53.83 bpm) than group-housed sows from both systems (45.92 & 46.72 bpm). Stall-housed sows had significantly higher heart rates whilst rooting (92.66 bpm) and drinking (99.58 bpm) than sows from the large group house (82.71 bpm - rooting & 90.03 bpm drinking). Stall-housed sows also had significantly higher heart rates whilst lying with their eyes open (66.30 bpm) compared with large group house sows (55.94 bpm).

Table 7.5 Mean heart rate response (in beats per minute) to specified behaviours, compared between systems

Behaviour	Stalls	Large Group	Small Group	p-Value
Basal HR	53.83 ^{a}	46.72 ^{b}	45.92 ^{b}	0.0172
Rooting	92.66 ^{a}	82.71 ^{b}	87.66 ^{ab}	0.0603
Drinking	99.58 ^{a}	90.03 ^{b}	96.92 ^{ab}	0.0518
Lying (eyes open)	66.30 ^{a}	55.94 ^{b}	58.00 ^{ab}	0.0362

^{a,b} Values without common superscript in same row are significantly different at $p<0.05$.

Graph profiles during feeding for all three systems were similar in shape (see Figure 7.4), showing an instantaneous rise at feed delivery, a sustained elevated heart rate during feeding followed by a gradual decrease once the food had been eaten.

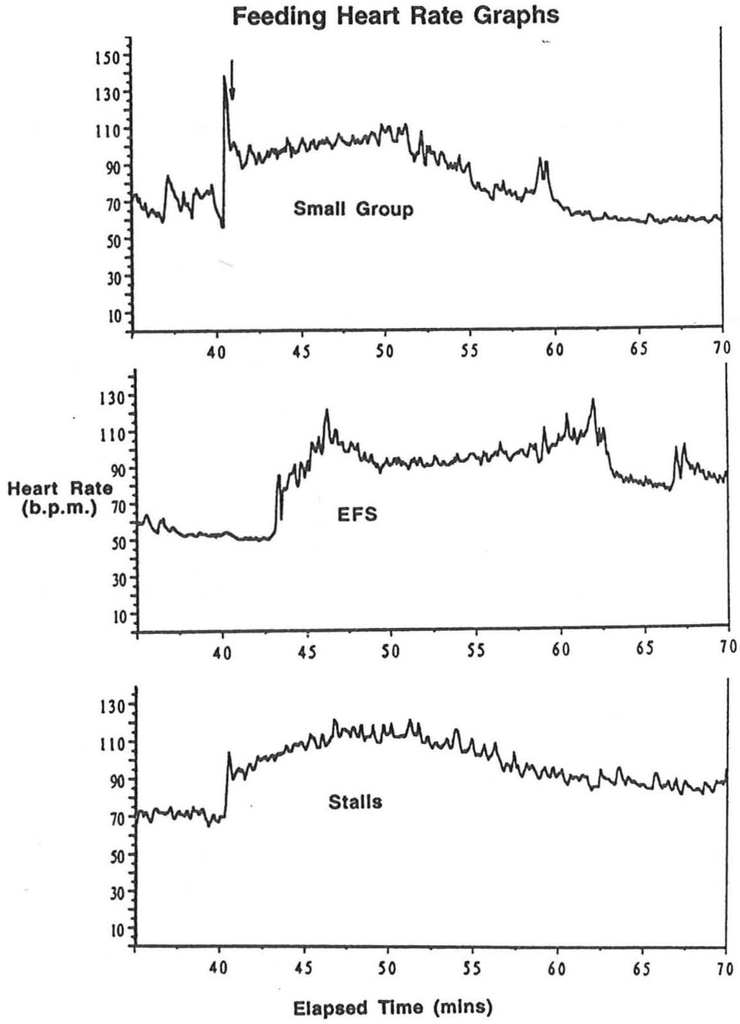


Figure 7.4 Graph profiles over feeding for sows from all three dry sow systems.

There were no significant differences between absolute peak values at feeding for all three systems (see Table 7.6). However, stall-housed sows had significantly higher average feeding heart rates (117.9 bpm) compared with sows in the small group (102.5 bpm) and large group (105.9 bpm).

Table 7.6 Mean heart rate response (beats per minute) to feeding for sows from all three dry sow systems.

Behaviour	Stalls	Large Group	Small Group	p-Value
Feeding (average)	117.9 ^{a}	105.9 ^{b}	102.5 ^{b}	0.0114
Feeding (peak)	149.1	135.5	154.8	0.1391

^{a,b} Values without common superscript in same row are significantly different at p<0.05.

However, because of the possibility of significant differences in heart rate during the specified behaviours being solely due to the addition effect of the significant differences in basal heart rate, it was decided to reanalyse the results as 'change from basal' (see Table 7.7).

With basal levels taken into account, there were no longer significant differences in heart rate for the behaviours of rooting, drinking and lying with eyes open. As before, there was no significant differences found between peak values at feeding. However, average heart rate values over feeding remained significantly different, with stall-housed sows higher (+64.06 bpm) than group-housed sows (+58.56 & +56.55 bpm).

Table 7.7 Mean change in heart rate (beats per minute) from basal during specified behaviours, for sows from all three systems.

Behaviour	Stalls	Large Group	Small Group	p-Value
Feeding (Avg.)	+64.1 ^{a}	+58.6 ^{b}	+56.5 ^{b}	0.0274
Feeding (Peak)	+95.1	+88.8	+108.8	0.1699
Rooting	+38.8	+35.9	+41.9	0.5229
Drinking	+45.7	+43.3	+51.0	0.2329
Lie (eyes open)	+12.5	+9.2	+12.2	0.7018

^{a,b} Values without common superscript in same row are significantly different at p<0.05.

7.3.4 Discussion

It is important that the results are related to any modification that the housing system may impose on heart rate. It must be remembered that the Small Group and the ESF systems offer both freedom of movement and the possibility of a wide variety of social interactions. Also, in both the Stall and Small Group systems, feeding takes place in close proximity to other sows.

Without accounting for the significant differences in basal heart rate, the results would seem to indicate an increased sympathetic nervous response to the studied behaviours in stall-housed sows compared with group-housed sows. However, with the basal rate considered, results for drinking, rooting and lying with eyes open lose their significance, and thus the elevated basal levels experienced by the stall-housed sows must be the single most important factor. The cause of this elevation could be lack of exercise, variation in housing temperature or a combination of the two.

Like all muscle, the heart must be forced to work regularly to maintain efficiency, and as such requires regular exercise. Activity alone is not sufficient; stall-housed sows may show either a decrease in overall activity compared with group-housed sows (Gravås, 1982, Carter & English, 1983), or an increase (Bengtsson et al, 1983, Cariolet & Dantzer, 1985), and yet suffer a greater incidence of cardiovascular disease (Ratcliffe et al, 1969). Schouten et al (1991) did not detect any change in resting heart rates between loose-housed or tethered sows, but in this may be due to the relatively short-term tethering carried out in the study (maximum 6-8 months). The sows used in our study had been kept in stalls over a period of 48-50 months, except during the farrowing period.

In terms of house temperature, all three buildings register similar maximum and minimum daily temperatures. However, both group-housed systems are straw-based, whereas the stall-house system has an uninsulated concrete floor. This gives rise to greater conductive heat-loss from the sow to the floor substratum in the stall house system. In an experiment conducted over 3 days during April 1993, average outside temperature during measurement ranged from +13.7°C to +16.4°C. House temperature did not vary significantly and averaged +16.6°C for the Large Group House, +17.1°C for the Small Group House and +18.8°C for the Stall House. However, there were significant differences between houses when a temperature probe was placed between a sow and the floor substratum. This sow/substratum interface temperature averaged +36.2°C for straw-based sows, but only +30.3°C for sows bedded on concrete.

Long-term, this represents a very large potential energy loss for sows housed on concrete, especially if whole-house temperature is not maintained at an optimum 21-22°C. This loss may be compounded by an inability to maintain body temperature by muscular exercise. Thus, physiological compensation may be achieved by an increase in metabolic rate with a corresponding increase in basal heart rate. A decrease of 5°C from this optimum temperature will result in a requirement for an additional 170g/day of food for sows in good condition and upto 300 g/day for thinner sows (English et al, 1977). Thus, the basal heart rate results indicate that the stall-housed sows probably have reduced cardiovascular fitness compared with group-housed sows in general.

With the basal levels taken into account, the response of stall-housed sows to feeding remains significantly higher than group-housed sows. This would seem to indicate the importance of feeding behaviour over the other behaviours studied. The importance of the feeding event has been demonstrated in studies of differences between stall and group-housed sows, in responsiveness to various stimuli (Broom 1986b, c, 1987). Schouten et al (1991) have demonstrated this difference to be partly blocked by a beta-adrenergic receptor blocker, and thus partly due to an increased sympathetic nervous response.

The peak values are also of interest, although they are non-significant. Both the Small Group and Large Group results could have been affected by locomotory activity and social encounters prior to feeding. In Small Group housed sows, social interactions can continue whilst feeding occurs. For the Large Group sows, once in the feeder station, they are free to eat their ration in a totally enclosed environment free from any visual contact with other sows. The Stall-housed sows have naso-naso contact with two neighbours, which gives rise to a number of aggressive interactions during feeding. These differences may account for the apparently lower peak in Large Group sows.

7.4 Study Three

Differences in heart rate of group-housed and stall-housed sows during specified behaviours in farrowing crates

7.4.1 Introduction

The restrictive environment imposed by farrowing crates greatly modifies the sow's behaviour both pre-partum and post-partum. On average, the sow spends only about four to five weeks per litter within the farrowing crate, but this is probably at the time when freedom of movement is most important, i.e. the period during which the sow displays characteristic maternal behaviour. Confinement prior to parturition frustrates nest-building behaviour, which can result in increased amounts of posture changing (Hansen & Curtis, 1981, Heckt et al, 1988 and Chapter 6 of this thesis). Confinement after parturition can influence suckling behaviour (Cronin & Smith, 1992a) and hinder the formation of the mother-offspring bond which is reinforced by naso-naso contact immediately after suckling (Whatson & Bertram, 1983) and by vocal communication and olfactory cues (Horrell & Eaton, 1984, Horrell & Hodgson, 1992a, 1992b). Confinement also influences the sow's posture during the lactation period, resulting in less time spent lying laterally, thus restricting piglets' access to the udder (Cronin & Smith, 1992b).

In the preceding experiment, it was demonstrated that long-term confinement of sows may lead to an increased sympathetic nervous response to certain stimuli, a fact that has also been reported by Schouten et al (1991). The primary aim of this experiment, was to determine the heart rate response of sows, whilst carrying out specified behaviours, during short-term confinement in farrowing crates. Other objectives were; 1) to determine any differences in heart rate response between sows which had previously gestated in confinement and sows which had previously gestated in an open system, and 2) to determine any differences in heart rate response between sows whilst they were in the dry sow system and the farrowing system.

7.4.2 Methods

The study was carried out on a total of 14 Large White x Landrace sows, within the farrowing crate house at the Animal Welfare Group's Pig Unit. All sows had been subjects of the previous study (Study Two) and were of similar age and stage of lactation. The sows were manually fed 2.5kg of feed, twice daily, at 0700 hrs and 1430 hrs. The feed was given in a single delivery, with the monitored sows being fed first in order to minimise any heart rate response due to anticipation. Approximately 20 minutes after feeding, the stockman delivered 2 litres of water into the feed trough, to supplement the nipple drinkers.

The sows were monitored from 30 minutes before afternoon feeding, to 120 minutes after feeding, and were under direct behavioural observation throughout this period. Specified behaviours that were recorded included feeding, rooting and lying with eyes open. These allowed comparison with the dry sow systems. Suckling bouts were also recorded, in order to determine heart rate response of sows from different dry sow systems, to a specific maternal behaviour event. Each sow was monitored on four consecutive days from day 7 of lactation to day 10 inclusive and the numerical results for each behaviour obtained and averaged in the way described earlier. For feeding and suckling, absolute peak values were measured, together with average values and also the change in heart rate from average level immediately preceding the measured behaviour to the absolute peak value. This was in order to determine how much of the heart rate increase was due to the stimulus of feed presentation or suckling event, rather than due to previous locomotory or postural input.

7.4.3 Results

When data from all sows, irrespective of dry sow system, are included in the analysis (see Table 7.8), there is no significant difference between average heart rate response for feeding (113.0 bpm) or suckling (106.5 bpm). However, the average heart rate responses for both these behaviours are greater than those during lying (73.8 bpm) and rooting (98.7 bpm), and heart rate during rooting is greater than lying. When these average heart rates are analysed by dry sow system, the average heart rate during lying is significantly lower than for any other behaviour. However, in stall sows, suckling elicits an average response (100.3 bpm) similar to rooting (96.0 bpm), and significantly lower than feeding (113.6 bpm), whereas in group sows, suckling elicits an average response (112.7 bpm) similar to feeding (112.3 bpm) and significantly higher than rooting (101.8 bpm).

Table 7.8 Mean heart rate response (beats per minute) to specified behaviours, of sows housed in farrowing crates.

Sample	Lying	Rooting	Suckling	Feeding	p-Value
Combined	73.8 ^{a}	98.7 ^{b}	106.5 ^{c}	113.0 ^{c}	0.0001
Stall sows	73.2 ^{a}	96.0 ^{b}	100.3 ^{b}	113.6 ^{c}	0.0001
Group sows	74.4 ^{a}	101.8 ^{b}	112.7 ^{c}	112.3 ^{bc}	0.0001

^{a,b,c} Values without common superscript in same row are significantly different at p<0.05.

When combining data for absolute peak values for suckling and feeding (see Figure 7.5), the peak value for feeding (130 bpm) is significantly higher than the peak value for suckling (115 bpm). However, analysing the data with respect to previous dry sow environment, reveals a significant difference between suckling and feeding peak values for sows previously housed in stalls (108 bpm vs. 132 bpm, p=0.0001), but no difference for sows previously housed in the large group (122 bpm vs. 129 bpm, p=0.3099).

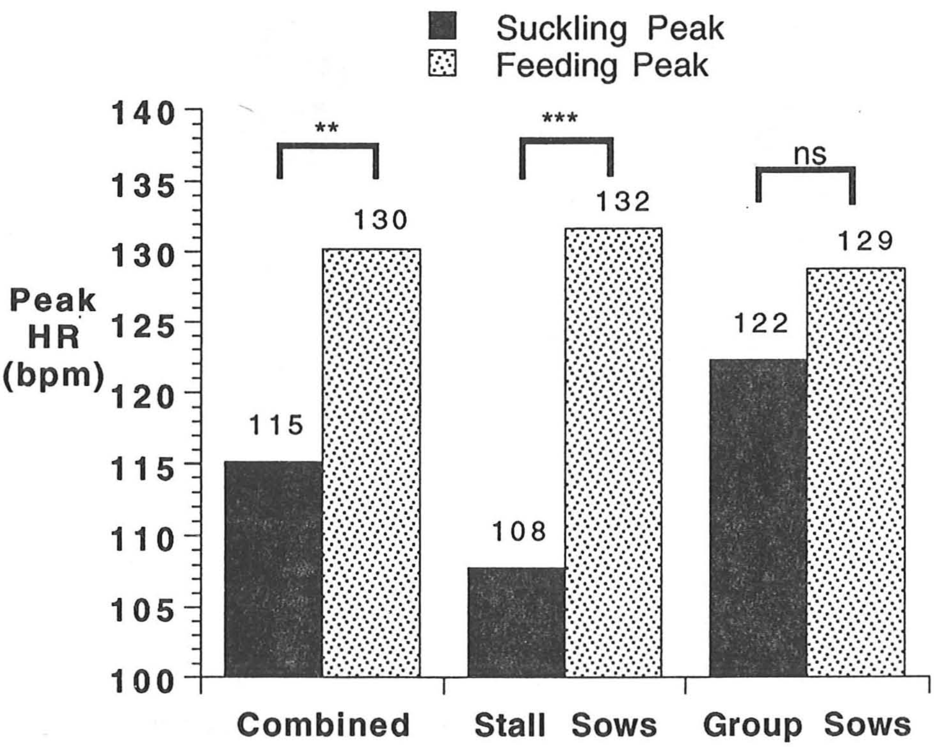


Figure 7.5 Mean peak heart rate response (beats per minute) of sows in farrowing crates during suckling and feeding. Levels of significance: ** p<0.01, *** p<0.001.

Similarly, when data for the change in heart rate from average levels prior to the event, to peak value for suckling and feeding are combined (see Figure 7.6), there is a highly significant difference between the changes for suckling (+29.5 bpm) and feeding (+44.4 bpm). When analysed with respect to previous dry sow environment, the difference between changes for suckling and feeding remains large for stall sows (24.7 bpm vs. 44.9 bpm, p=0.0001), but for group sows is much smaller (34.4 bpm vs. 43.9 bpm, p=0.0358).

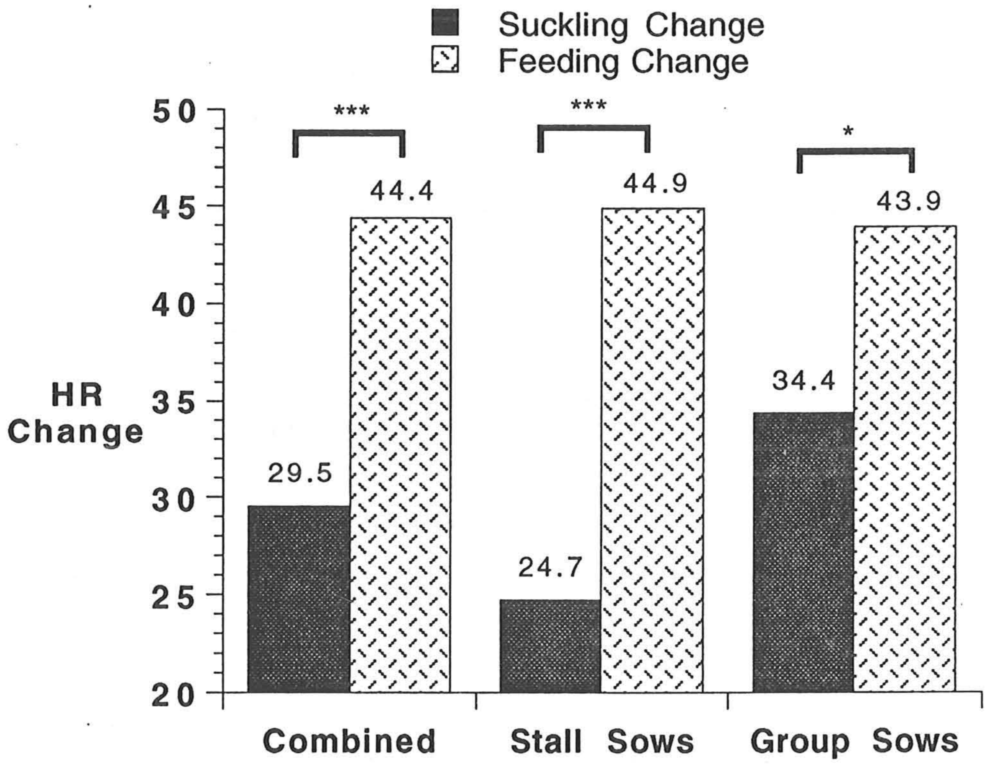


Figure 7.6 Mean change in heart rate (beats per minute) from before to during specified behaviour, of sows in farrowing crates during suckling and feeding. Levels of significance: * p<0.05, *** p<0.001.

There were no significant differences in average heart rate between stall sows in crates and group sows in crates, during lying, rooting or feeding (see Table 7.9). There were also no significant differences in peak heart rate or change in heart rate during feeding. However, there were significant differences, between stall and group sows, in heart rate responses to suckling. Sows previously housed in groups had significantly higher average heart rate (112.7bpm vs. 100.4 bpm, p=0.047), peak heart rate (122.3bpm vs. 107.9bpm, p=0.031) and change in heart rate at suckling (+34.4bpm vs. +24.7bpm, p=0.013) than sows previously housed in stalls.

Table 7.9 Mean heart rate (beats per minute) during specified behaviours, for sows from different dry sow systems housed in farrowing crates.

Behaviour	Large Group Sows in Crates	Stall Sows in Crates	p-Value
Lying (eyes open)	74.4	73.4	0.799
Rooting	101.8	96.1	0.264
Suckling (Average)	112.7 [a]	100.4 [b]	0.047
Feeding (Average)	112.3	113.6	0.751
Suckling (Peak)	122.3 [a]	107.9 [b]	0.031
Feeding (Peak)	128.8	131.7	0.653
Suckling (Change)	+34.4 [a]	+24.7 [b]	0.013
Feeding (Change)	+43.9	+44.9	0.810

[a,b] Values without common superscript in same row are significantly different at $p<0.05$.

Within the dry sow conditions, there were significant differences in heart rate between stall sows and group sows during feeding (average heart rate and change in heart rate), rooting and lying with eyes open (see Table 7.10). However, following short-term confinement within farrowing crates, there were no significant differences in heart rate between stall sows and group sows, during these behaviours. Heart rate responses to feeding had diminished (peak, average and change) for crated stall sows and increased (average and change) for crated group sows. Heart rate during lying and rooting increased for both sets of sows in crates.

Table 7.10 Mean heart rate response (beats per minute) to specified behaviours, between sows in the dry sow system and the farrowing system.

	Dry sow System		Farrowing System		
Measure	Stall	Group	Stall	Group	p-Value
Feed (Peak)	149.1 [a]	135.5 [ab]	131.7 [ab]	128.8 [b]	0.111
Feed (Average)	117.9 [a]	105.9 [b]	113.6 [ab]	112.3 [ab]	0.128
Feed (Change)	+60.7 [a]	+34.3 [b]	+44.9 [ab]	+43.9 [b]	0.016
Lying	66.3 [b]	55.9 [a]	73.2 [bc]	74.4 [c]	0.001
Rooting	92.7 [b]	82.7 [a]	96.0 [b]	101.8 [b]	0.003

[a,b,c] Values without common superscript in same row are significantly different at $p<0.05$.

7.4.4 Discussion

The results seen in Table 7.8 confirm that heart rate is influenced by behaviour. The previous study (Section 7.3) demonstrated the importance of the feeding event, which resulted in the highest heart rate recorded for any of the behaviours studied. The results of this study show similarly high average heart rate response to the suckling event, although peak values (see Figure 7.4) and change in heart rate (see Figure 7.5) are significantly lower. The results also appear to show that group sows have a higher response to suckling than stall sows. There are no differences in average or peak heart rates between feeding and suckling for group sows, whereas responses to suckling for stall sows are significantly lower than feeding responses. In all measures of suckling heart rate, group sows had a greater response than stall sows (see Table 7.9)

Cronin & Smith (1992b) have reported that sows housed in crates spent less time engaged in pre-suckling behaviours and consequently had shorter suckling bouts than sows housed in farrowing pens. This may indicate that sows farrowing in confinement cannot form strong mother-offspring bonds, which may consequently decrease the importance of behaviours which keep this bond reinforced. Stall sows have been shown to be less active (Ekesbo et al, 1978, Jensen, 1979, 1980, 1981, Gravås, 1982, Carter & English, 1983) and also less responsive (van Putten, 1980, Wiepkema et al, 1983, Dantzer et al, 1986, Broom, 1986b, 1987) to most stimuli, the exception being presentation of food (Broom, 1986b). This inherent unresponsiveness of stall sows may in part explain the difference in reactivity to suckling. Conversely, the result obtained for group sows may be demonstrating high reactivity to the suckling event due to frustration of mother-infant interaction or distress at physical restriction.

Further effects of short-term confinement are reported in Tables 7.9 and 7.10. Within the dry sow conditions, stall sows had higher heart rates during lying, rooting, drinking and feeding. The majority of this difference was due to higher basal rates within the stall system, the factors for which have been discussed in the previous study (Section 7.3). However, when this basal rate effect was taken into account, although there were no longer any differences between systems in heart rate during lying, rooting and drinking, a difference in response to feeding remained. This was attributed to increased sympathetic nervous stimulation, as proposed by Schouten et al (1991). Within the farrowing crates, there were no longer any differences in heart rate between stall sows and group sows during lying, rooting or feeding.

The occurrence of suckling once per hour meant that there were no clearly distinguishable low basal levels, like those seen within the dry sow systems. The fact that in the farrowing crates, there were no differences between stall and group sows, in heart rate response to feeding, either indicates that basal heart rate levels had equalised between systems, or that there was little difference between sympathetic nervous response. In either case, the fact that there was no disparity between sows from confined and loose dry sow systems would seem to indicate that short-term confinement within crates is a disturbing experience for sows which have gestated in the open and elicits stress responses.

7.5 Study Four

The effect of agonistic encounters on the heart rate of group-housed sows

7.5.1 Introduction

A major problem reported by many commercial producers keeping sows in group housing systems, is that of inter-sow aggression and bullying, which can have a severe effect both in terms of physical injury and production. This aggression appears to be particularly prevalent during two periods, namely; 1) during and after mixing of sows back into the herd following farrowing and service, and 2) around the time of feeding. The consequences for production can be highly detrimental at both these times. Sows subjected to high levels of aggression on mixing may suffer hormonal upset leading to failure of embryo implantation and return to service. Sows subjected to aggression at feeding may be deprived of sufficient ration (Csermely & Wood-Gush, 1986, Edwards et al, 1993), especially within group feeding systems, and hence lose condition and give birth to litters with low viability.

The aim of this experiment was to determine the effect of different degrees of agonistic social interaction, on the heart rate of sows, to give an indication of the short-term stress response to social challenge.

7.5.2 Methods

A total of nine Large White x Landrace sows were chosen from the large group system on basis of order of going to the feeder as recorded on the ESF computer over the previous seven days. The heart rate monitors were fitted 30 minutes prior to the computer cycle switch over at 1500 hrs. Sows behaviour at the feeder entrance, was continuously recorded by direct observation together with video-recorder backup. The time on the receivers and video clock were synchronised in order to be able to pinpoint behavioural events on the numerical data.

Agonistic social interactions were categorised into two types:
Type 1 - Agonistic social encounter involving only visual threat. Loser moves away and avoids physical confrontation with winner.
Type 2 - Agonistic social encounter involving physical contact. Loser moves away only after bite or knock from winner.
This therefore gave four classifications of agonistic social behaviour:
i) Winner - Threat encounter
ii) Loser - Threat encounter
iii) Winner - Physical encounter
iv) Loser - Physical encounter
Not all sows monitored gave results for all four classifications because of different positions held in the social hierarchy. Some sows never lost an encounter, and some never won. Thus, although nine sows were monitored, the total number of sows within each classification was either six or seven. Results were averaged from six recordings for each sow in each classification. The behavioural and graphical data were combined as in the previous studies, and subsequent numerical data analysed to give peak heart rate and change in heart rate from previous average to peak. It was not possible to calculate an average heart rate during the majority of encounters because of the extremely short time period over which they occurred.

7.5.3 Results

When results for both types of encounter were combined (see Table 7.11), there were no significant differences in peak heart rate or change in heart rate between winners and losers, but there was a weak tendency for losers to have a greater change in heart rate than winners. Sows involved in a physical encounter had higher peak heart rate and greater change in heart rate than sows involved in a non-physical or threat encounter.

Table 7.11 Mean heart rate (HR) response (beats per minute) to social encounters, compared by encounter outcome.

Parameter	Win Encounter	Lose Encounter	p-Value
Peak HR	115.0	126.3	0.2667
HR Change	+38.7	+52.8	0.1238
	Physical Encounter	**Threat Encounter**	
Peak HR	137.7 [a]	105.3 [b]	0.0003
HR Change	+61.1 [a]	+32.1 [b]	0.0005

[a,b] Values without common superscript in same row are significantly different at $p<0.05$.

However, as stated above, some sows never won an encounter, and some never lost an encounter. If the results are analysed as above without taking this fact into consideration, some sows appear in both categories whereas others appear only in one. This could result in an artificially high or low value if a sow which only appears in one category has an unusually high or low heart rate. Therefore, the data were reanalysed using a Wilcoxon signed-rank test, which omitted the unpaired values (see Table 7.12). Using this statistical method, there was a greater tendency for losers to have a higher peak heart rate, and larger change in heart rate than winners.

Table 7.12 Mean heart rate (HR) response (beats per minute) to social encounters compared by encounter outcome.

Parameter	Win Encounter	Lose Encounter	z-value	p-Value
Peak HR	114.0	132.7	-1.719	0.0856
HR Change	+41.8	+58.1	-1.897	0.0578
	Physical Encounter	**Threat Encounter**		
Peak HR	140.4 [a]	110.0 [b]	-2.805	0.0050
HR Change	+63.5 [a]	+35.8 [b]	-2.803	0.0051

[a,b] Values without common superscript in same row are significantly different at $p<0.05$.

When the results are analysed in terms of all four classifications with all values included, (see Table 7.13), the sows showed an increase in heart rate ranging from between +30 to +75 beats per minute, when participating in an agonistic social encounter. Sows losing a physical agonistic encounter had significantly higher peak values and a significantly greater change in heart rate, than sows from the other three classifications.

Table 7.13 Mean heart rate (HR) response (beats per minute) to social encounters, compared by encounter outcome.

Measure	Encounter Outcome Win Physical	Win Threat	Lose Physical	Lose Threat	p-Value
Peak HR	125.3 ^{b}	104.7 ^{b}	150.2 ^{a}	105.9 ^{b}	0.0005
Change	+46.7 ^{b}	+30.7 ^{b}	+75.5 ^{a}	+33.4 ^{b}	0.0001

^{a,b} Values without common superscript in same row are significantly different at $p<0.05$.

Only three of the sows studied gave results in all four classifications, which was too small a sample size for statistical results to be meaningful, when ANOVA was carried out on these sows alone.

7.5.4 Discussion

The results confirm that sows show a stress response to social encounter, regardless of whether they involve physical contact, or whether they win or lose. The results obtained for sows in physical encounters definitely contain an element of increased locomotory activity, but this cannot wholly explain the rise seen in sows which lose these encounters. This large increase must be indicative of a greater stress response for these sows.

In terms of welfare, these results may be applied to group housing situations. It must be stated that the stress response elicited by these interactions is very transient, and as such, single or very infrequent encounters may not unduly affect the welfare of the individual sows concerned. However, if encounters are persistent, and there is little chance of avoidance, the stress response may become chronic rather than acute, and will undoubtedly affect the welfare of the individual.

Group housing systems that employ group feeding will result in poor welfare for certain subordinate sows, who have to compete for food or go without. Group systems that employ Electronic Sow Feeder systems, in some respects offer a choice of competition, or a choice of "opting out", in the knowledge that ration intake should be unaffected. The results noted above support the observations of Mendl et al (1992) who report three social strategies within the house studied. Whereas the high and middle success groups are readily involved in physical agonistic encounters, the low success group prefer to avoid aggression and thus only become involved in threat encounters in the majority of cases.

CHAPTER 8

Comparison of muscular conformation and bone strength of stall-housed and group-housed sows

8.1 Introduction

Intensification of livestock farming has, in general, lead to higher stocking densities and therefore less space per animal. The ultimate development has been housing systems in which the animals are tethered, or confined in stalls, crates or cages. This confinement has resulted in modification or cessation of many of the animal's normal behaviours and alteration of both anatomical and physiological parameters.

The skeletal system of a breeding female mammal performs two highly important roles. Firstly, it has the role of structural support, which alone necessitates a certain degree of mechanical strength, and secondly, it provides a "reserve" for calcium and phosphorus which may be required for fœtal development during gestation, and milk production during lactation. The demands of gestation and lactation can cause severe depletion of calcium & phosphorous from the mother's bones, if sufficient dietary levels of these minerals are not maintained. This can make the bones susceptible to fracture; a susceptibility which may be increased if the bones are weakened in any way, as a consequence of previous environmental factors.

The confinement imposed by permanent stalls and tethers offers no opportunity for exercise, and this affects both cardiovascular fitness (see Section 7.3) and possibly muscular fitness. Regular exercise is needed for any muscle (cardiac or skeletal) to develop in bulk and contractile strength. Without this, the muscle will atrophy and become weak, and muscular conformation will be altered. Exercise is also required to maintain bone composition and strength and with decreased mechanical loading, calcium is mobilised from the bone by an unknown mechanism, under hormonal control (Lanyon, 1984, 1987).

The objectives of these studies were to investigate differences in muscular conformation and bone strength between sows housed long-term, in groups or permanent stalls.

8.2 Study One

Differences in locomotory muscle conformation between stall-housed and group-housed sows

8.2.1 Introduction

There are some 5-600 individual skeletal muscles in the domestic pig, made up of an active part, the muscle belly, and the passive tendons which connect the muscle at either end (the origin and the insertion). The physical size of each muscle is dependent on the amount of exercise it is subjected to, on a regular basis. With regular exercise, any muscle will increase in size, and it is the physiological diameter which determines the muscle's strength. Thus, if muscular exercise is greatly limited, as within confined housing systems, it is possible that muscular diameter and strength will decrease. Any differences in the diameter of muscles used for locomotion and posture changes, may result in difficulty of movement, and therefore have welfare consequences for the sow.

The physiological diameter is different from the anatomical diameter in the vast majority of cases. The latter involves simply bisecting the muscle belly at its widest point, to give an even cross-section. The former, however, takes into account the direction of muscle fibres, and involves cutting all muscle fibres within the belly, perpendicularly to direction in which they run (see Figure 8.1).

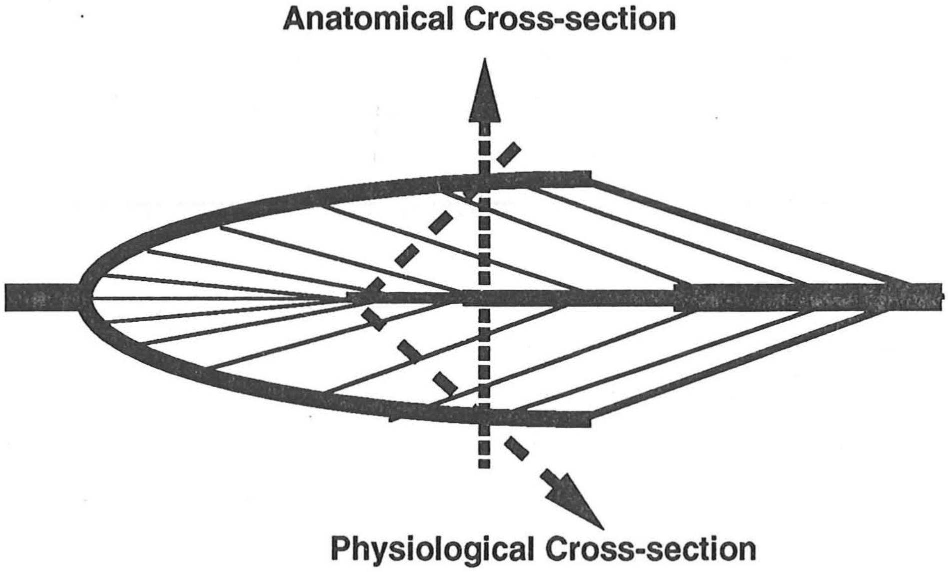


Figure 8.1 Diagrammatic representation of the differences between the anatomical and physiological diameters for a simple unipennate muscle.

Thus, with measurement of the physiological diameter being so difficult, because of the complex structure of many muscles, a comparison between systems was made in terms of individual muscle weight.

The objective of this study was to determine differences in muscular conformation due to lack of exercise, between sows housed in two different dry sow systems, by comparing the weight of specific locomotory muscles.

8.2.2 Method

The study was carried out on 18 non-pregnant Large White x Landrace sows of similar age, parity and genetic stock housed in two different dry sow systems; 1) Large group with ESF (n=10), and 2) Permanent stalls (n=8). After slaughter, 14 individual locomotory muscles, five from the left forelimb and nine from the left hindlimb, were dissected out. The muscles that were removed were:

Forelimb: Deltoid, Biceps Brachii, Triceps Brachii, Brachialis and Extensor Carpi Radialis (see Plate 8.1).

Hindlimb: Superficial Gluteal, Tensor Fascia Latae, Biceps Femoris, Semitendinosis, Gracilis, Sartorius, Cranial Tibial, Fibularis Tertius and Soleus/Gastrocnemius (see Plate 8.2).

These were chosen partly on the basis of their perceived importance during locomotion (see Chapter 4) and partly on the basis of ease of identification and removal. After removal, the muscle bellies were dissected away from their tendons, and carefully cleaned of fascia and surface fat. The cleaned muscles were then weighed.

A relative proportion of each muscle to total body weight was then calculated by dividing the absolute muscle weight in grams by the total live bodyweight in kilograms. This removed any differences in muscle weight that were purely as a result of a heavier total body weight. The results were analysed using a Student's two-sample t-test.

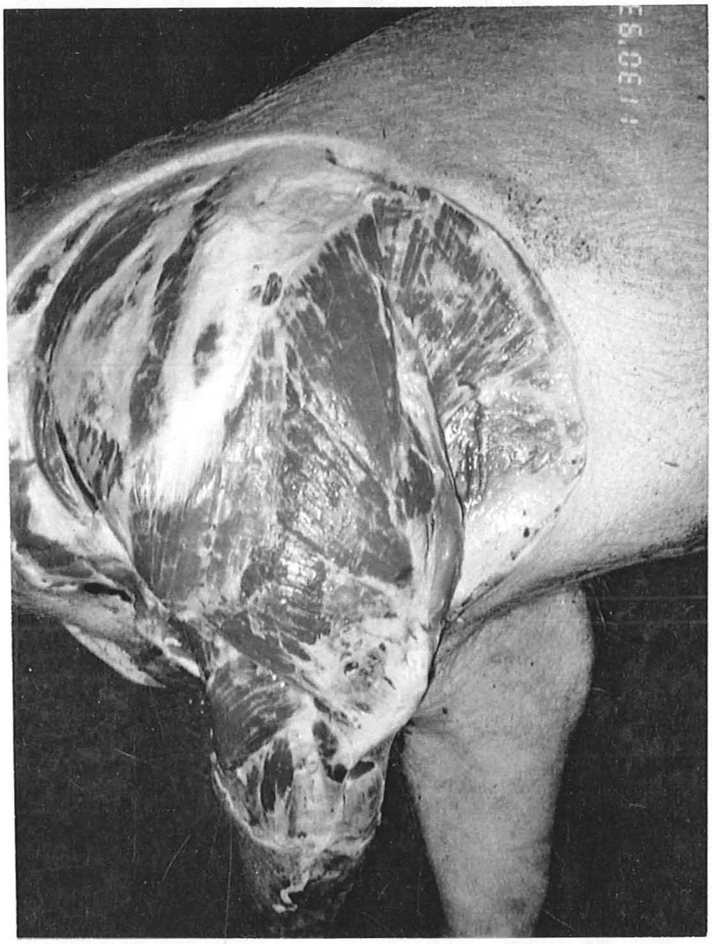


Plate 8.1 The muscles of the forelimb prepared for dissection and removal.

Plate 8.2 The muscles of the hindlimb prepared for dissection and removal.

8.2.3 Results

When absolute muscle weights were compared (see Table 8.1), there were significant differences in muscle weight between the systems, for nine muscles (two in the forelimb and seven in the hindlimb), and tendency towards difference for a further four muscles.

Table 8.1 Mean absolute muscle weights (grams) of sows housed long-term in two dry sow systems.

Muscle	Group Sows	Stall Sows	p-Value
Deltoid	243.2 ^{a}	199.7 ^{b}	0.0001
Biceps Brachii	179.2	172.5	0.4398
Triceps Brachii	1853.3	1701.7	0.1001
Extensor Carpi Radialis	280.0	252.9	0.0541
Brachialis	234.1 ^{a}	189.7 ^{b}	0.0076
Superficial Gluteal	579.3 ^{a}	448.4 ^{b}	0.0006
Tensor Fascia Latae	582.1 ^{a}	466.4 ^{b}	0.0006
Biceps Femoris	2954.4	2719.9	0.1096
Semitendinosis	1076.6 ^{a}	935.1 ^{b}	0.0058
Gracilis	624.4 ^{a}	478.9 ^{b}	0.0003
Sartorius	73.5 ^{a}	48.6 ^{b}	0.0013
Cranial Tibial	54.2	47.7	0.0592
Fibularis Tertius	189.4 ^{a}	146.4 ^{b}	0.0002
Soleus/Gastrocnemius	1107.5 ^{a}	919.2 ^{b}	0.0022
Total Body Weight (kg)	242.0 ^{a}	219.2 ^{b}	0.0074

^{a,b} Values without common superscript in same row are significantly different at $p<0.05$.

However, there was also a significant difference in total bodyweight between systems, which is a factor for the difference in individual muscle weights (see Table 8.2)

Table 8.2 Correlation between bodyweight and individual muscle weight for sows from both dry sow systems combined.

Muscle	r-Value	p-Value	Muscle	r-Value	p-Value
Deltoid	0.806	0.0001	**Biceps F.**	0.391	0.1096
Biceps B.	0.198	0.4298	**Semitend.**	0.622	0.0058
Triceps B.	0.400	0.1001	**Gracilis**	0.750	0.0003
ECR	0.461	0.0549	**Sartorius**	0.699	0.0013
Brachialis	0.607	0.0076	**C. Tibial**	0.453	0.0592
S. Gluteal	0.727	0.0006	**F. Tertius**	0.764	0.0002
TFL	0.747	0.0004	**Sol/Gast.**	0672	0.0022

By comparing proportional muscle weights, the difference due to total bodyweight is removed, and differences due to the amount of exercise become apparent (see Table 8.3 and Figure 8.2). There were significant differences in proportional muscle weight between the systems, in eight muscles (one forelimb and seven hindlimb muscles), and a tendency for difference in one muscle. There were no significant differences in five muscles.

Table 8.3 Mean proportional muscle weight of sows housed long-term in two dry sow systems.

Muscle	Group Sows	Stall Sows	p-Value
Deltoid	1.005 [a]	0.910 [b]	0.0070
Biceps Brachii	0.743	0.787	0.3228
Triceps Brachii	7.635	7.749	0.6551
Extensor Carpi Radialis	1.154	1.152	0.9543
Brachialis	0.964	0.866	0.0892
Superficial Gluteal	2.398 [a]	2.040 [b]	0.0195
Tensor Fascia Latae	2.397 [a]	2.124 [b]	0.0030
Biceps Femoris	12.186	12.383	0.6731
Semitendinosis	4.453 [a]	4.266 [b]	0.0058
Gracilis	2.574 [a]	2.186 [b]	0.0037
Sartorius	0.302 [a]	0.220 [b]	0.0026
Cranial Tibial	0.223	0.217	0.5535
Fibularis Tertius	0.782 [a]	0.666 [b]	0.0045
Soleus/Gastrocnemius	4.570 [a]	4.183 [b]	0.0444

[a,b] Values without common superscript in same row are significantly different at $p<0.05$.

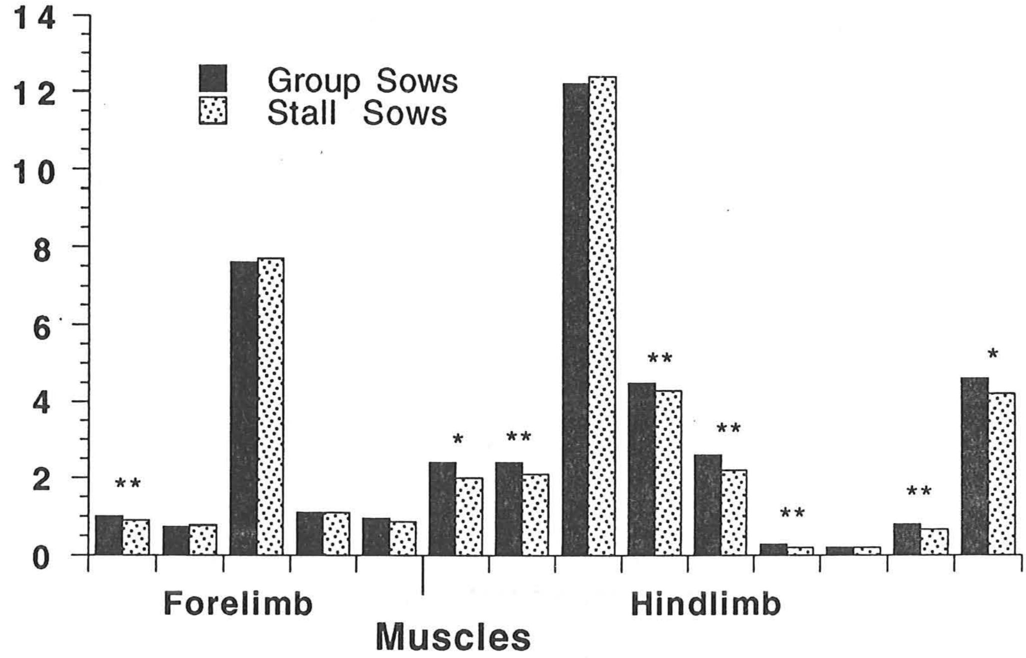


Figure 8.2 Mean proportional muscle weight of sows from the two dry sow systems. Level of significance: * p<0.05, ** p<0.01.

8.2.4 Discussion

The results indicate that housing sows in long-term confinement affects muscular conformation, resulting in decreased proportional muscle weight for certain locomotory muscle and hence, decreased muscular strength. It probable that the differences in muscle proportion would be greater if body fat content was taken into account. The stall sows had far less subcutaneous fat than the group sows, and thus skeletal muscle should form a higher proportion of total body weight for stall sows. It may therefore be expected that even though absolute muscle weight is lower for stall sows, proportional muscle weight would be similar because of the higher total proportion of muscle in the body. Therefore, because of the perceived differences in body fat, it is likely that the differences in proportional muscle weight are even greater in real terms.

The consequences of this conformational difference may be two-fold. The decreased muscular strength for stall sows may result in difficulty when carrying out basic movements such as standing and lying (see Chapter 9). In the dry sow system, this can compromise the sow's welfare. However, in the farrowing system, difficulty in controlling lying and standing may have welfare implications for the piglets, in terms of increasing the chance of death due to crushing.

The second consequence may be an altered susceptibility to lameness. With weaker muscles, there is a greater chance of the sow slipping during lying and standing and incurring physical damage. There is also the possibility that different conformation affects the incidence of lameness, by changing joint angles and increasing strain on particular muscles or ligaments rendering them more prone to injury.

8.3 Study Two

Differences in bone breaking strength between group-housed and stall-housed sows

8.3.1 Introduction

The modern domestic pig has been genetically selected to maximise weight and length of back for meat production. Consequently, its body shape has changed and the anatomical and physiological demands on the skeletal system have increased, even without any modification that housing systems may impose.

A great deal of research in pigs has focused on the effects of dietary factors on bone strength (e.g. Rousseaux et al, 1981, Reinhart & Mahan, 1986, Hall et al, 1991), whilst others have attempted to highlight differences due to age (Arthur et al, 1983), sex (Bayley et al, 1975) and breed (Grandhi et al, 1986). The effects of exercise have also been investigated (Anderson et al, 1971, Perrin & Bowland, 1977) and its importance in the development of bone during the growth stage is well-documented.

However, little has been done to investigate the effects that long term confinement may have on the bone strength in sows. Similar studies on the bone strength of confined laying hens has shown that those confined in cages without sufficient room to carry out locomotory and wing-flapping behaviours, have humeri and tibia that are significantly weaker than birds housed in a non-restrictive environment (Knowles & Broom, 1990).

The objective of this study was to determine any difference in the strength of the humerus and femur between sows housed long-term, in permanent stalls and open groups.

8.3.2 Methods

The study was carried out on non-pregnant Large White X Landrace sows housed in two different dry sow housing systems: Permanent Stalls (n=8) and Group-housed (n=10). All sows were of similar age (seventh to ninth parity) and from the same genetic stock. They were being replaced under ongoing herd policy and were slaughtered on-farm, as part of another project. After weighing, the sows were slaughtered by lethal injection of pentabarbitone. The left humerus and left femur were dissected out, and muscle, ligament and tendon attachments removed, taking care not to cut the bone surface. The bones were measured to determine length and shaft diameter. The diameter was taken as the outside width of bone perpendicular to the direction of application of the breaking force.

Breaking strength was tested using an Instron Universal Testing Machine. The bones were supported at each end by supports separated by a distance of 20 cm (see Plates 8.3 & 8.4). A force was then applied at a single point on the midshaft, at a rate of 5 $mm.min^{-1}$ until the bones broke cleanly. The maximum force exerted in kilograms was then read from the Force-deformation curve plotted on the chart recorder (see Figure 8.3).

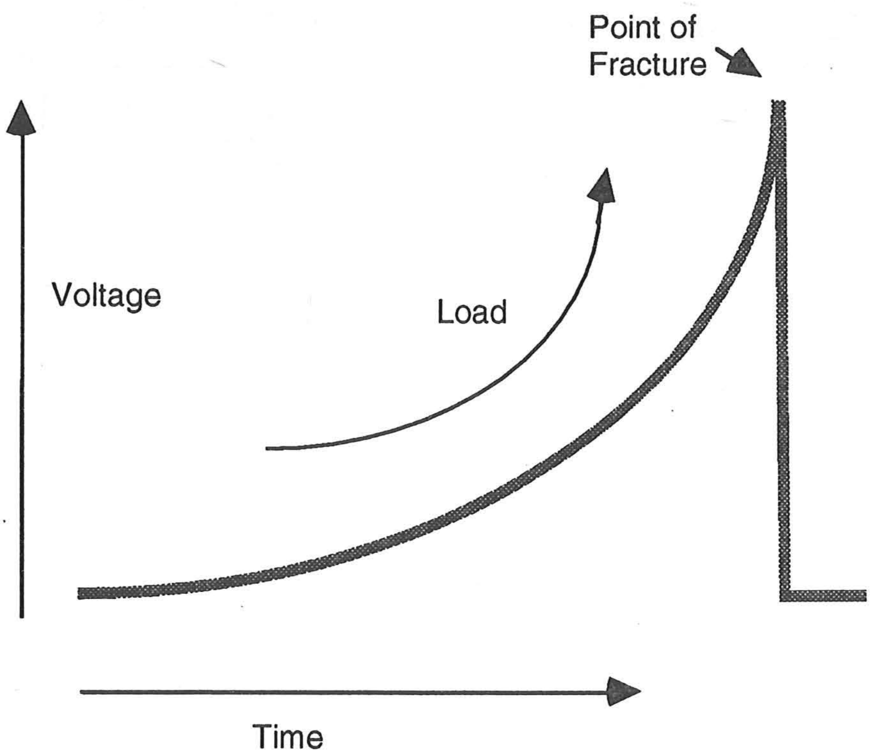


Figure 8.3 Diagrammatic representation of a force deformation curve.

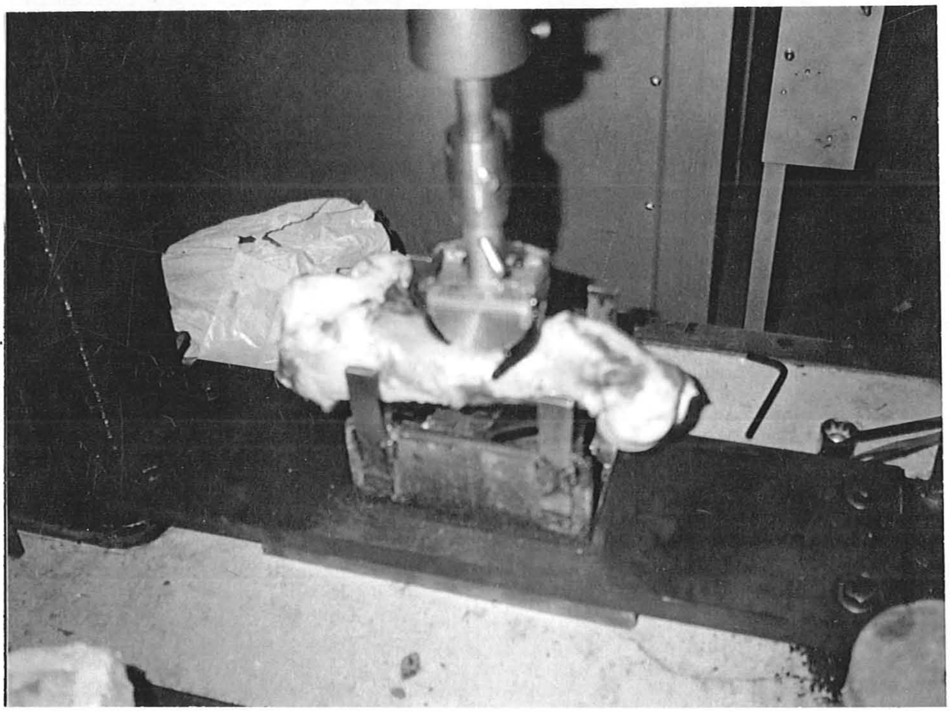


Plate 8.3 The humerus in position on the Universal Tester.

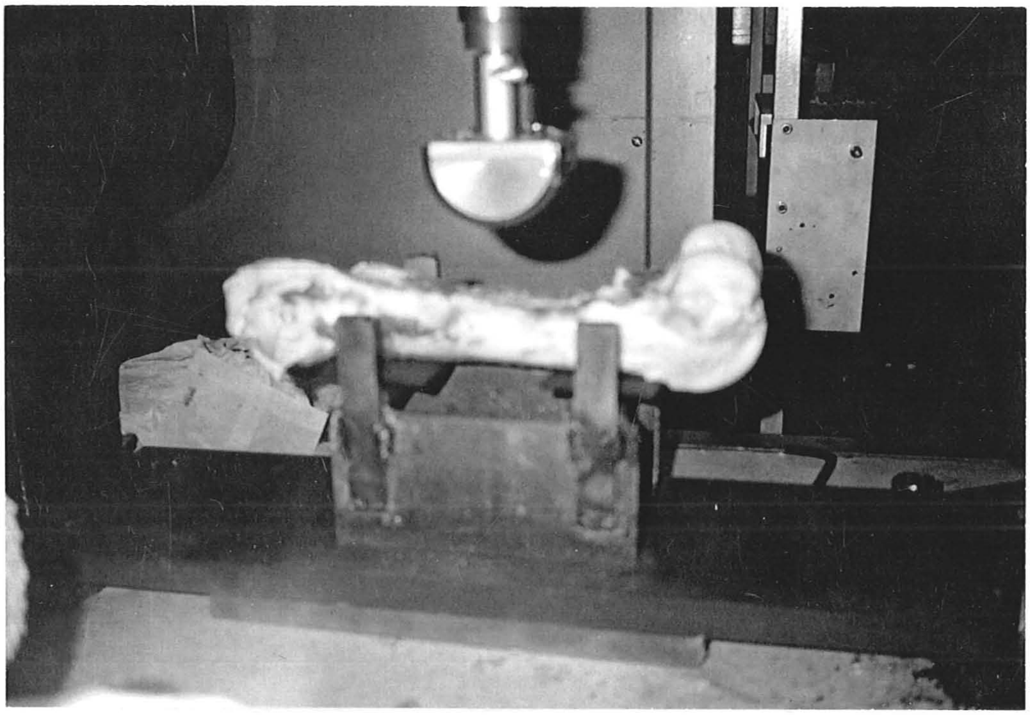


Plate 8.4 The femur in position on the Universal Tester.

8.3.3 Results

Using a Student's two-sample t-test, humeri and femurs from stall-housed sows had significantly lower breaking strength (742.8 kg and 808.9 kg respectively) than those from group-housed sows (1158.4 kg and 1120.4 kg respectively - see Figure 8.4).

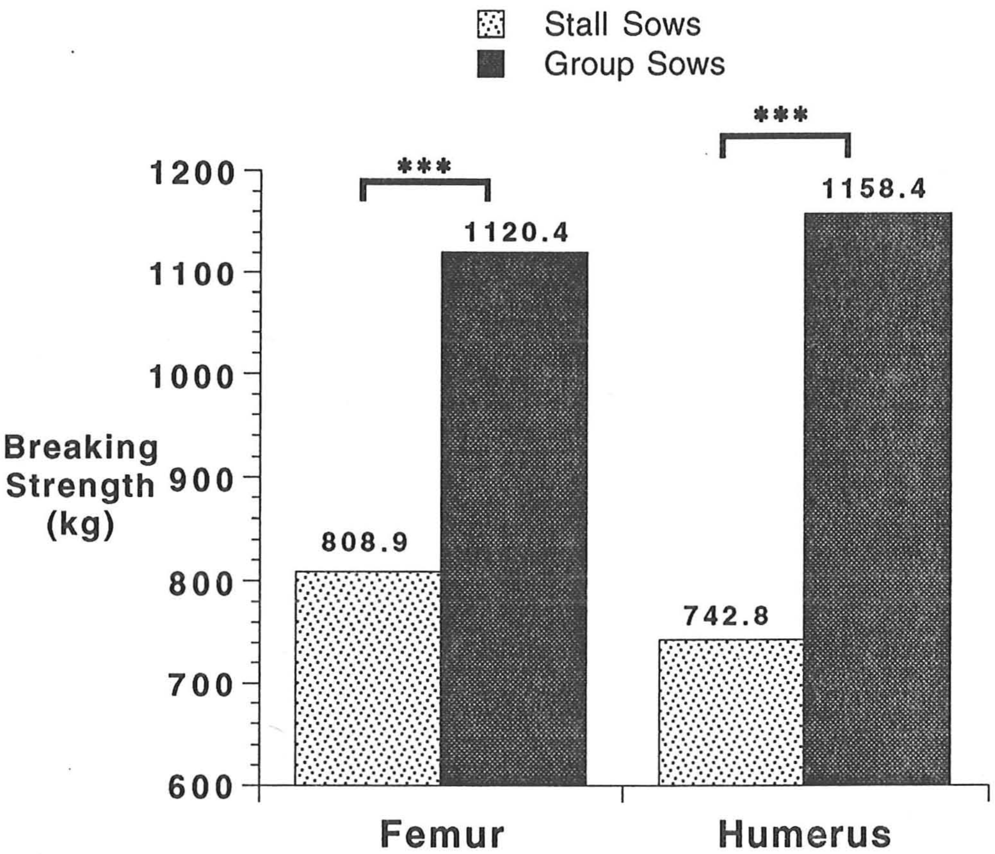


Figure 8.4 Mean bone strength (kg exerted at fracture) of sows from two dry sow housing systems. Level of significance: *** $p<0.001$.

There were no differences between systems, in bone dimensions (see Table 8.4). Both humeri and femurs were similar in length and width.

Table 8.4 Mean bone dimensions for sows from two dry sow housing systems.

Dimension (cm)	Group Sows	Stall Sows	p-Value
Humerus Length	236.7	233.8	0.5363
Humerus Width	44.8	46.2	0.2862
Femur Length	273.1	266.5	0.2595
Femur Width	36.6	37.2	0.4845

There was also no correlation between bone strength and bone dimension, across both systems combined, and within each system separately (see Table 8.5).

Table 8.5 Correlation between bone strength and bone dimensions (all sows)

Bone	Dimension	r-Value	p-Value
Humerus	Length	0.070	0.7768
Humerus	Width	0.290	0.2289
Femur	Length	0.259	0.2839
Femur	Width	0.133	0.5862

When all 18 sows are included, bone strength is positively correlated with total body weight (see Figures 8.5 and 8.6). It could be that the majority of the difference in bone strength between the systems is due to the difference in total body weight, so this hypothesis will now be explored.

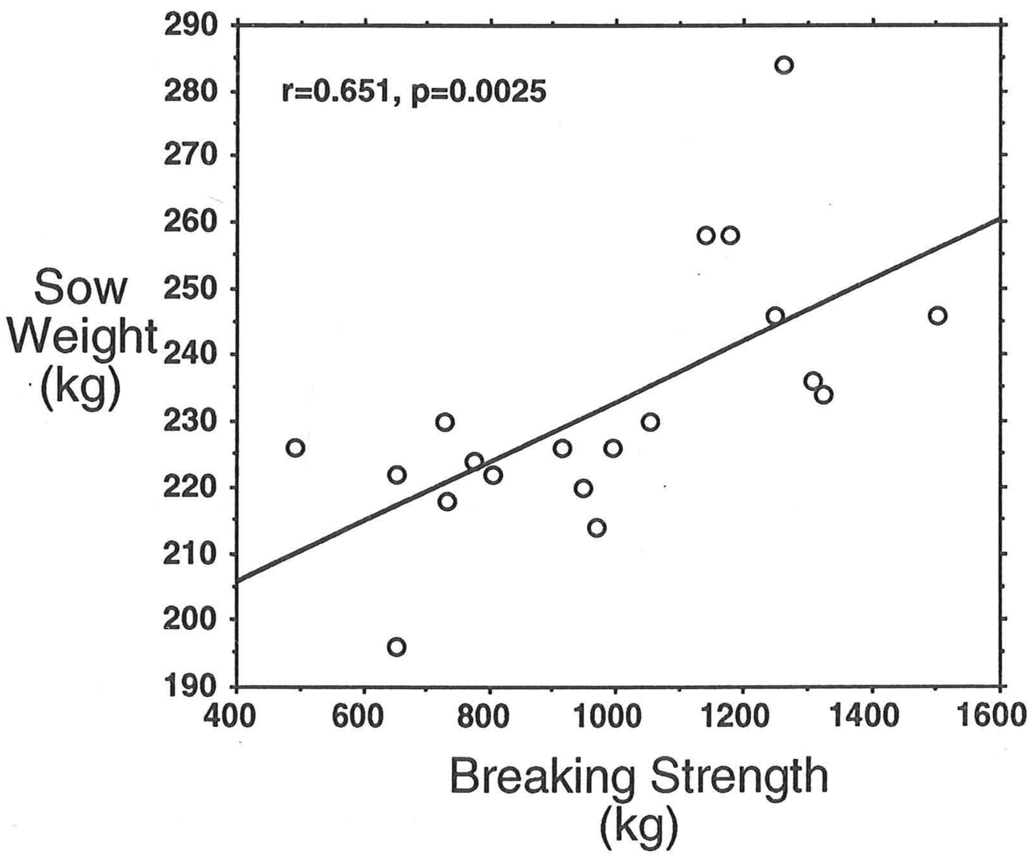


Figure 8.5 Correlation between humerus breaking strength and total bodyweight (all sows)

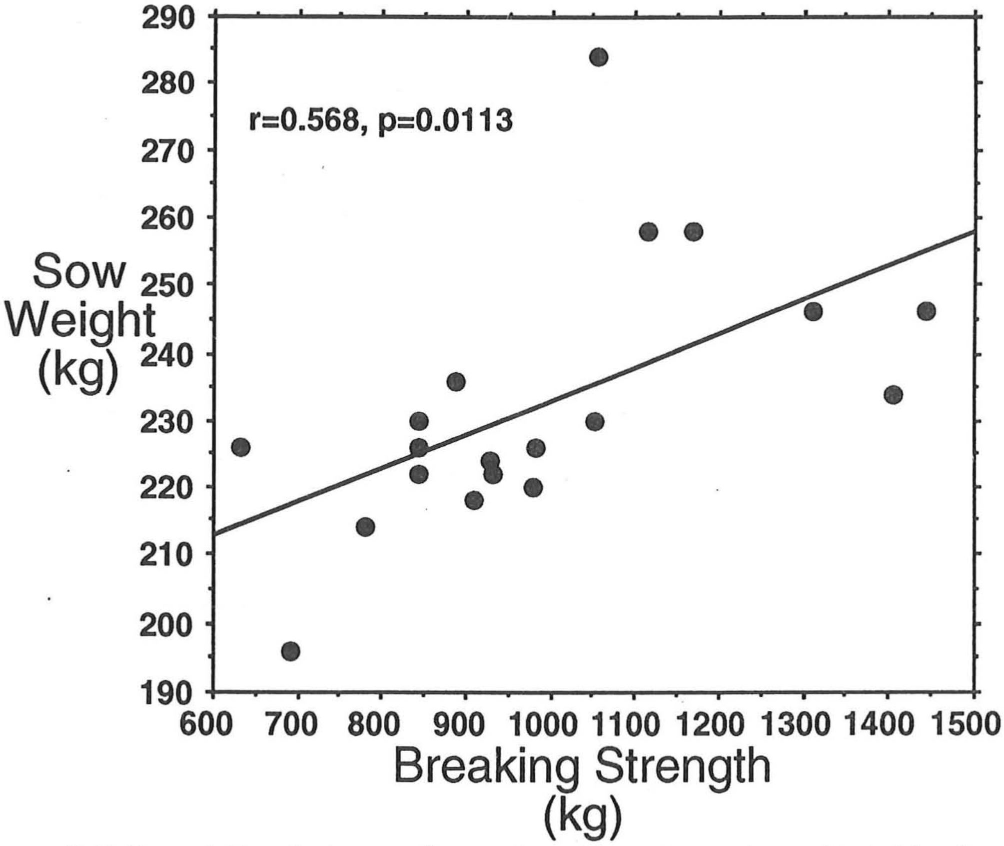


Figure 8.6 Correlation between femur breaking strength and total bodyweight (all sows).

When the data were re-analysed by multiple regression with the body weight variable removed, there were still significant differences in both humerus and femur strength, between systems (p=0.0074). Also, there was no correlation between bone strength and total bodyweight within each system (see Table 8.6).

Table 8.6 Correlation between bone strength and total bodyweight, within each system.

System	Bone	r-Value	p-Value
Group Sows	Humerus	0.493	0.1231
Group Sows	Femur	0.240	0.4763
Stall Sows	Humerus	0.016	0.9708
Stall Sows	Femur	0.333	0.4207

As individual muscle weight increases, volume and cross-section will enlarge, leading to an increase in the force that the muscle can transmit. Thus, absolute muscle weight can give an indication of the amount of force exerted through origin and insertion. Addition of the individual muscle weights for each limb, will therefore indicate the potential muscular force that can act on the bone.

There was positive correlation between humerus breaking strength and the total weight of the five forelimb locomotory muscles (see Figure 8.7).

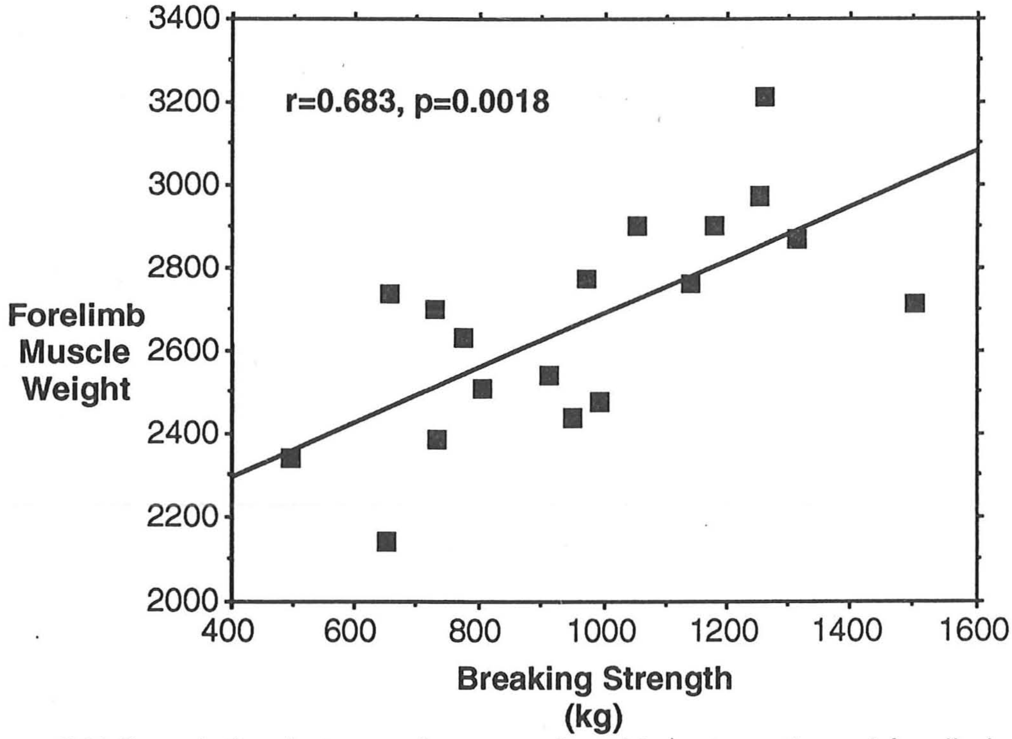


Figure 8.7 Correlation between humerus breaking strength and forelimb muscle weight.

There was positive correlation between femur breaking strength and the total weight of the nine hindlimb locomotory muscles (see Figure 8.8)

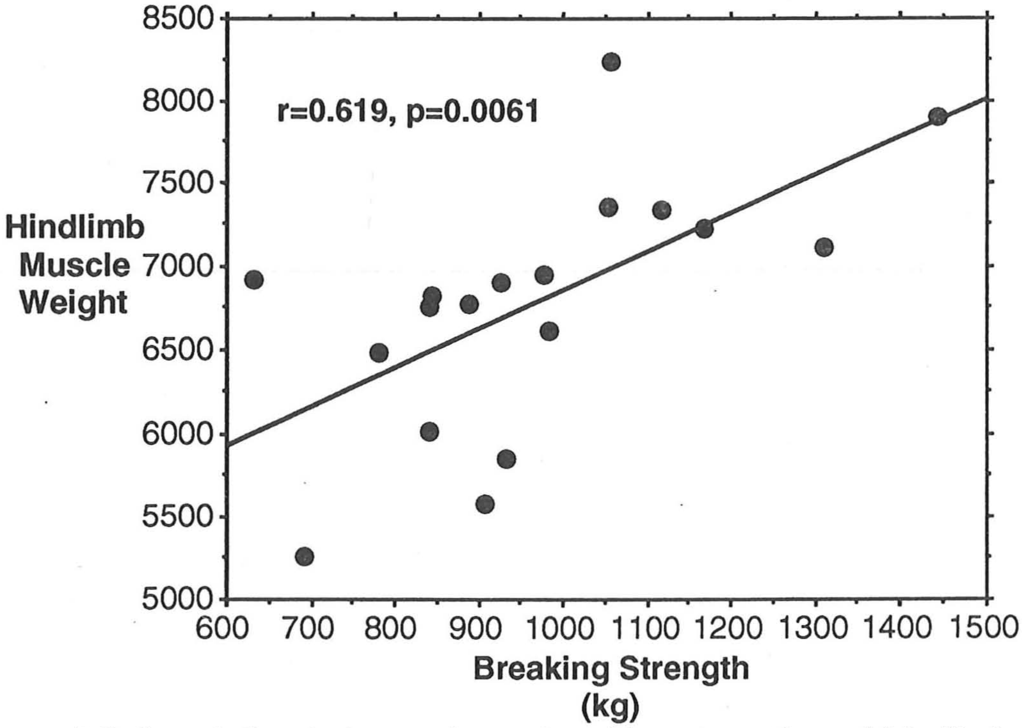


Figure 8.8 Correlation between femur breaking strength and hindlimb muscle weight.

Total hindlimb and forelimb muscle weights were strongly correlated with total body weight. However, the total hindlimb muscle weight and total forelimb muscle weight of the stall-housed sows were significantly lighter than those of the group-housed sows even when the data were re-analysed by multiple regression with the body weight variable removed (p=0.0082).

8.3.4 Discussion

The results indicate that confinement leads to a decrease in bone strength. Factors that may have influenced the difference between stall-housed sows and group-housed sows include genetic strain (Rowland et al, 1972), diet and reproduction. Genetic strain is not a possible factor in this study, as both sets of sows come from the same stock and in some instances are litter-mates. In terms of diet, there have been numerous studies into the effects of differing levels of calcium and phosphorus in the diets on bone strength (e.g. Reinhart & Mahan, 1986, Combs et al, 1991, Hall et al, 1991), but in this study, the diet is the same for both systems, and therefore not a factor.

Reproduction has also been reported to have an effect on bone strength, due to the high calcium demands placed on the female during fœtus growth, lactation and, in the case of poultry, egg-shell formation. Kornegay et al (1973) found that the breaking strength of sows' femurs decreased with parity number. This effect was also demonstrated by Nimmo (1980) using two sets of gilts, one set having undergone a single gestation and lactation, and the other remaining unserved. In this study, sows were matched for parity number (seventh to ninth) and there was no difference in average parity, between systems.

Therefore, it would appear that the difference in bone strength between systems is due to the amount of exercise that each system permits. Exercise has been implicated in studies on bone strength, with much work having been carried out on hens, where large numbers are easily obtainable for comparison. Meyer & Sunde (1974) increased bone breaking strength of caged layers by a few minutes on an exercise machine. McLean et al (1986) found stronger tibiae in aviary layers than caged layers, and noted that aviary birds typically moved seven times as far during a specified time period. Knowles & Broom (1990) have also noted similar differences in bone strength between hens housed in different systems. Lanyon (1984) has proposed that with decreased dynamic loading, calcium is mobilised from the bone under hormonal control. The mechanism by which this occurs is not known (Lanyon, 1987).

The results of this study initially indicate total bodyweight to be a major factor influencing bone strength (see Figures 8.5 and 8.6), when both systems are combined. However, when the data was reanalysed with the bodyweight variable removed, the bones from stall-housed sows were still significantly weaker than those from group-housed sows. This indicates that total bodyweight is not the most important factor in the difference between systems. It would appear that the difference in bone strength and the difference in total bodyweight have developed independently of each other. Indeed, confinement during the growing phase may have an effect on skeletal and muscular development. The sows used in this study from one herd were found to have significantly shorter body length when housed as gilts in stalls than when loose-housed (see Chapter 9). This may illustrate that exercise is important to allow growth and development of bone and muscle to their full genetic potential.

A more important factor may be that of total muscular force acting upon a bone. As stated earlier, the force a muscle can exert is dependent on the physiological cross-section of the muscle belly. Therefore, addition of the individual muscle weights can give an indication of the potential force that can be exerted on the bone during movement. The results shown in Figures 8.7 and 8.8 would appear to indicate that as the potential force increases, bone strength increases, which is in line with the theory of dynamic loading influencing calcium mobilisation, proposed by Lanyon (1984). The fact that stall-housed sows still have lighter locomotory muscle weights than group-housed sows even when the total bodyweight variable is removed, indicates the effect that confinement has on locomotory muscle strength.

This decrease in bone strength may also influence the incidence of lameness, in conjunction with the differences in muscular conformation. Lameness has been reported as being more frequent in confined sows (Bäckström, 1973, Tillon & Madec, 1984). Data from herd records of a local large-scale commercial producer show differences in the percentage of culls due to lameness between different sow housing systems; outdoor units = 3.4 %, indoor group units = 10-15%, and stall units = 24%. These would seem to support the idea that there may be a higher incidence of lameness within stall and tether systems. Krohn & Munksgaard (1993) have also noted a greater incidence of hock inflammation in dairy cows housed in confinement, illustrating the fact that confinement poses locomotory problems in a number of domestic species.

CHAPTER 9

The effects of farrowing and dry sow housing conditions on time taken to lie down and stand up

9.1 Introduction

An increase in intensification of livestock farming has, in general, lead to higher stocking densities and therefore less space per animal. The ultimate development has been housing systems in which the animals are tethered, or confined in stalls, crates or cages. This confinement has resulted in a loss of ability to exercise, and modification of an animal's posture-changing behaviours.

Work by Herlin (1990) and Krohn & Munksgaard (1993) on tied and loose dairy cows, has found significant differences in the times taken for lying down, between the two groups. The action was divided into two stages, the first stage being the preparation period up to the first knee touching the ground, and the second stage being from the end of this to completion of the action. Both these stages were longer for tied cows, suggesting difficulty of movement for cows with no ability to exercise. Tied cows also showed a greater incidence of interruptions to the action (Krohn & Munksgaard, 1993).

The modern domestic pig has been genetically selected to maximise weight and length of back for meat production. Consequently, its body shape has changed and the physical acts of standing up and lying down have become difficult, and relatively uncontrolled, even without any modification that housing systems may impose. The importance of livestock spatial requirements in the design of housing has been noted for pigs (Petherick, 1983) and more specifically for sows in confinement (Baxter & Schwaller, 1983, Curtis et al, 1989). The majority of sows in the European pig industry currently gestate in permanent stalls or tethers, and farrow and lactate in crates. Baxter & Schwaller (1983) found that the majority of UK. farrowing crate designs are based on the static space requirements of the sow and do not make allowance for the dynamic space requirements during standing and lying. This result was duplicated by Curtis et al (1989) following a study of U.S. farrowing crates.

Confinement of sows during any stage of the reproductive cycle will greatly restrict the amount of locomotory exercise they can perform and will result in a decrease in both muscular fitness (see Chapter 8) and cardiovascular fitness (see Chapter 7). It is also possible that confinement will alter lying and standing behaviours compared with sows without any spatial restrictions. Any difficulty in the movements necessary for standing and lying, may indicate poor welfare for the sow and, because the majority of piglet mortality is attributable to over-lying by the sow when she lies or stands clumsily, there may also be welfare implications for her litter.

The objectives of these studies were to compare the time taken to lie down in sows from different dry sow systems, and to investigate factors that affect or influence this behaviour. The times taken to lie down and stand up were then investigated within a farrowing crate system, in order to determine any effects on the number of piglets killed by crushing.

9.2 Study One

A comparison of lying behaviour of stall-housed and group-housed sows, and the relationship with body dimensions

9.2.1 Introduction

Comparative studies of the effects of housing conditions on the length of time taken to lie down, have been carried out on tied and loose-housed dairy cows by Herlin (1990) and Krohn & Munksgaard (1993). Both reported tied cows to take longer to lie down, lie for shorter duration and have more interruptions to the lying down behaviour. These studies concluded that exercise must be the important factor in this difference. The effects of dry sow housing conditions on lying behaviour is an important area for research, not only because of the large number of sows kept in confinement, but also because of the implications for piglet survival that any disruption to normal lying behaviour that this confinement may have.

The objectives of this study were to investigate the time taken for sows to lie down in different dry sow housing systems, and to determine any relationships between the time taken and body dimensions of the sow. The effects of the differences in muscular conformation (see Chapter 8) were also investigated.

9.2.2 Methods

The categorisation of the behaviours of standing and lying into stages are discussed in General Methods (see Chapter 4). The time taken to lie down was investigated, using 32 Large White X Landrace sows of similar age and stage of gestation, housed in two different dry sow systems at the University Pig Unit: 1) Permanent Stalls (n=8), 2) A large group with an Electronic Sow Feeder (ESF) system (n=24).

The sows were measured to determine body length from crown to tailhead, height to the point of shoulder and breadth across shoulders. The stall-housed sows were recorded remotely using a static camera (Panasonic WV-CD110AE) linked to a time-lapse video-recorder (Panasonic AG-6720A) set on Normal mode. The group-housed sows were recorded manually using a hand-held camcorder (Panasonic NVG-3B) from the aerial observation platform situated in the house. Each sow was video-recorded four times during lying, and average duration calculated for each separate stage and for the whole behaviour following frame-by-frame analysis of the tapes.

Differences between stage and total times were investigated by Analysis of Variance. Relationships between times and body parameters, and between times and muscular conformation, were investigated using Pearson Correlation.

9.2.3. Results

It was soon apparent that group-housed sows lie down in two different ways. On the majority of occasions, lying down is carried out with the assistance of an aid. Most often this aid is a wall, but can also be the recumbent body of another sow. On other occasions, sows lie down unaided in the open. Therefore, Analysis of Variance was carried out on various measures of behaviour during the following:

1: Stall-housed sows lying down. (n=8)
2: Group-housed sows lying down unaided in the open. (n=24)
3: Group-housed sows lying down against the wall. (n=24)

There were significant differences between all three lying categories in total time taken to lie down. (Figure 9.1)

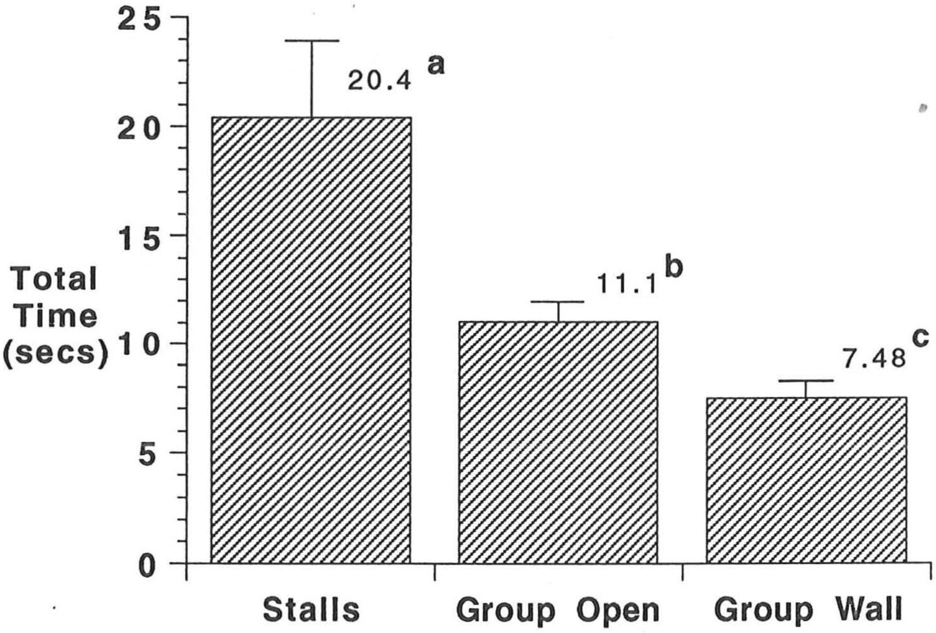


Figure 9.1 Mean total time (+ s.e.) taken to lie down by dry sows in stalls and in groups with and without the aid of a wall. [a,b,c] Values without common superscript are significantly different at $p<0.05$.

The stall-housed sows took significantly longer to lie down in all stages compared with group-housed sows. Group-housed sows lying down in the open took significantly longer carrying out Stage 2 than group-housed sows lying down against a wall (see Table 9.1).

Table 9.1 Time taken to lie down, in seconds, for sows in stalls or groups.

Stage Times	Stall	Group-Open	Group-Wall	p-Value
1	3.01 [a]	2.22 [b]	1.74 [b]	0.0063
2	7.44 [a]	3.09 [b]	0.93 [c]	0.0001
3	2.09 [a]	1.12 [b]	1.24 [b]	0.0004
4	5.23 [a]	2.61 [b]	2.06 [b]	0.022
5	2.66 [a]	2.04 [ab]	1.53 [b]	0.0075
Total Time	20.42 [a]	11.07 [b]	7.48 [c]	0.0001

[a,b,c] Values without common superscript in same row are significantly different at $p<0.05$.

When a comparison of body dimensions was carried out (see Table 9.2), it was found that the body length of stall-housed sows was significantly shorter than that of the group-housed sows, even though they were the same age and from the same genetic stock. This may indicate the importance of exercise for growth and development of muscle and bone to its full genetic potential. There was no difference in the height or breadth of the sows.

Table 9.2 Mean body dimensions of sows housed in stalls or groups.

Dimension (mm)	Stall Sows	Group Sows	p-Value
Length	1526.4 [a]	1581.6 [b]	0.0138
Height	831.1	829.3	0.9782
Breadth	399.5	414.0	0.1788

[a,b] Values without common superscript in same row are significantly different at $p<0.05$.

In group-housed sows, there was no correlation between body dimensions and time taken to taken lie down, either in terms of total time or in individual stage times (see Table 9.3).

Table 9.3 Correlation between total time taken to lie down and body dimensions for group-housed sows.

Lying Type	Body Dimension	r-Value	p-Value
Group Wall	Length	0.270	0.2028
"	Height	0.231	0.2777
"	Breadth	0.282	0.1818
Group Open	Length	0.184	0.4011
"	Height	0.003	0.9893
"	Breadth	0.311	0.1493

In stall-housed sows too, there was no correlation between body height or breadth and total time or individual stage times (see Table 9.4).

Table 9.4 Correlation between total time taken to lie down and body dimensions in stall-housed sows.

Lying Type	Body Dimension	r-Value	p-Value
Stalls	Height	0.326	0.4303
Stalls	Breadth	0.576	0.1354

However, there was a positive correlation between body length and some stages of lying (see Table 9.5), and in total time taken to lie down (see Figure 9.2).

Table 9.5 Correlation between body length and time to lie down (stall sows).

Stage	Average Time	r-Value	p-Value
1	3.01	0.476	0.2327
2	7.44	0.701	0.0530
3	2.09	0.084	0.8450
4	5.23	0.719	0.0446
5	2.66	0.327	0.4297
Total	20.42 sec	0.846	0.0082

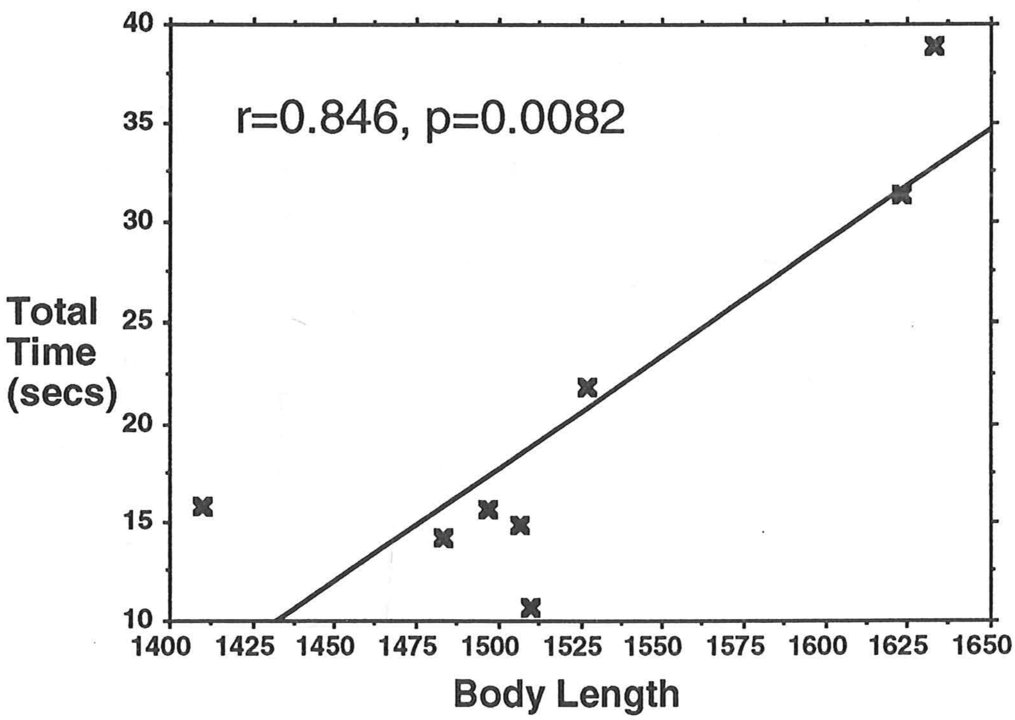


Figure 9.2 Correlation between body length and total time taken to lie down for stall-housed sows.

Time taken to lie down was then correlated with the results obtained from the studies carried out in Chapter 8, to determine whether there were other anatomical factors that affected lying, especially in group-housed sows.

There was no correlation between bone strength and time taken to lie down in stall sows, group sows lying down against the wall or group sows lying down in the open. Similarly, there was no correlation between absolute muscle weights and time taken to lie down in either system. When muscle proportions were considered, there was no correlation between muscle proportions and time taken to lie down for stall-housed sows or group-housed sows lying down against a wall. However, there were positive correlations between certain individual muscle proportions and both total time taken to lie down and individual stage times, in group-housed sows lying down in the open (see Table 9.6).

Table 9.6 Correlations for which p<0.05, between time taken to lie down and muscle proportions in group-housed lying down in the open.

Stage of Lying	Muscle	r-Value	p-Value
Stage 1	Extensor Carpi Radialis	0.843	0.0175
	Brachialis	0.792	0.0339
	Soleus/Gastrocnemius	0.892	0.0070
Stage 2	NONE	-	-
Stage 3	Brachialis	0.758	0.0485
	Superficial Gluteal	0.755	0.0498
	Gracilis	0.787	0.0357
	Soleus/Gastrocnemius	0.774	0.0413
Stage 4	Extensor Carpi Radialis	0.965	0.0004
	Superficial Gluteal	0.805	0.0289
	Soleus/Gastrocnemius	0.858	0.0136
Stage 5	NONE	-	-
Total	Extensor Carpi Radialis	0.957	0.0007
	Soleus/Gastrocnemius	0.807	0.0283

9.2.4 Discussion

These results indicate that, given enough space to manoeuvre, sows can lie down in a controlled fashion regardless of physical size. However, from the results shown in Figure 9.1 and Table 9.1, it is also clear that sows confined in stalls, experience difficulty when lying down. All stages of lying down took significantly longer for stall-housed sows than for group-housed sows. Also, the total time taken for stall-housed sows to lie down increased as sow body length increased. This result would appear to indicate that current commercial gestation stalls do not allow the sow sufficient space to lie down easily.

The space requirement of sows has been investigated by Baxter & Schwaller (1983) and Curtis et al (1989). Both found that the majority of farrowing crates available in the UK and US, were designed around the static space requirements of the animals and did not take into account the amount of space required during standing and lying. During these behaviours, there is a degree of sideways and forwards and backwards motion, outside the bounds of the static requirements. With these dynamic space requirements taken into account, the vast majority of gestation stalls and farrowing crates are too small in width and length, to allow standing and lying to be carried out, free from spatial restriction. Restriction of this kind during movement may impose severe biomechanical stress on the sow (Baxter, 1984), which may be a factor causing the higher incidence of lameness seen in sows housed in confinement (Bäckström, 1973, Tillon & Madec, 1984 - see Chapter 8).

Within a loose housing system, the results shown in Table 9.6, indicate that when lying down in the open, without any spatial restriction, the amount of time taken to lie down depends on the proportional weight of certain individual locomotory muscles. All these results are positive correlations between time taken and muscle proportion, with the larger the proportion, the longer the time taken. This study has implicated only a few muscles that are crucial for the control of lying down. These are the Extensor Carpi Radialis, Brachialis, Superficial Gluteal, Gracilis and Soleus/Gastrocnemius. There are probably other muscles that are involved in the action of lying down, but these were not among the 14 muscles selected for the dissection and analysis carried out in Chapter 8.

It is interesting, that during Stage 5 there is no correlation between time and muscle proportion. This may be because of the uncontrollable nature of this stage of movement. Stages 1-4 involve relatively stable postures, which can be maintained or controlled by muscular action. At the start of Stage 5, there is a slight movement of the pelvis to one side, resulting in the centre of gravity of the hindquarters falling outside the vertical support of the legs. Thus, the posture cannot be held by muscular action, and the hindquarters fall to the floor, in an uncontrollable way.

The fact that there is no correlation between proportional muscle weight and time for stall-housed sows or group-housed sows lying down next to a wall, suggests that confinement or spatial restriction results in Stages 1-4 also losing some muscular control. Thus, piglets may be at greater risk of death due to overlying in confined farrowing systems which impair the control of all stages of lying. A result reported in Chapter 8 was that stall-housed sows have smaller proportional muscle weights than group-housed sows. Hence, stall-housed sows placed into a loose farrowing system would have a reduced ability to lie down in a controlled way, which may also increase the risk of piglets being killed by overlying.

Thus, the degree of confinement or spatial restriction affects the time taken to lie down. Sows housed in stalls experience difficulty in lying down, and this difficulty increases with the body length of the sow. These sows also lose any element of muscular control during lying. Therefore, it can be stated that in respect of carrying out basic movements, the welfare of these animals is poorer than that of group-housed sows.

9.3 Study Two

An investigation into lying and standing behaviour of stall-housed sows, and the relationship with body dimensions

9.3.1 Introduction

The results from Study One indicated that sows housed in stalls, had more difficulty when lying down than did loose-housed sows. As stated above, the majority of this difficulty was probably due to the restriction of dynamic spatial requirements and became greater as the body length increased. However, because of the small sample size, and the fact that the sows studied had been housed in confinement for longer than is usual on commercial units, it was decided to repeat the study on confined sows housed in a commercial stall house.

The objectives of this study were therefore to study further, the effects of confinement on time taken to lie down and stand up, and also to investigate other factors, such as stage of gestation, length of time that the sow had been confined and breed. Furthermore, production figures were investigated to determine whether there was any link between time taken to lie down and stand up in confinement and piglet mortality.

9.3.2 Methods

Study Two was carried out on 28 sows which were a mixture of Large White X Landrace (n=10), and LargeWhite/Landrace X Hampshire (n=18). All sows were housed in a single permanent stall system, on a commercial unit. The sows were of varying age and stage of gestation. The amount of time that they had been confined also differed, as there was no policy of returning sows to the same dry sow system following service.

The sows were measured to determine body length from crown to tailhead, height to the point of shoulder and breadth across shoulders. The sows were recorded using a static camera (Panasonic WV-CD110AE) attached to a time-lapse video recorder (Panasonic AG-7620A) set to record in normal time mode. Each sow was recorded for a total of eight hours, and the average stage times and total times taken to lie and stand were calculated using frame-by-frame analysis.

The computerised production records for the herd used in this study were also analysed to determine the percentage of piglets killed by over-lying in the last four parities. The percentage killed was then correlated with total times taken to lie and stand, and also sow body dimensions to determine any relationships.

9.3.3 Lying Down

9.3.3.1 Results

There were no significant differences in body dimensions between different breeds (see Table 9.7).

Table 9.7 Mean body dimensions of stall-housed sows of different breeds.

Dimension (mm)	LW/Lr X Hampshire	LW X Landrace	p-Value
Length	1503.5	1521.0	0.5451
Height	792.9	778.7	0.3580
Breadth	400.6	411.1	0.3943

The average time taken for all sows to lie down, was 18.4 seconds. There was a tendency for Hampshire Cross sows to lie down quicker, and there were significant differences between breeds, in time taken to carry out stages 2 and 3 (see Table 9.8).

Table 9.8 Mean individual stage times and total times, of stall-housed sows of different breeds.

Stage Times	All Sows	LW/Lr xHampshire	LWxLandrace	p-Value
1	1.67	1.62	1.77	0.3771
2	8.40	7.20 ^{a}	10.80 ^{b}	0.0380
3	1.43	1.27 ^{a}	1.74 ^{b}	0.0065
4	5.10	5.06	5.18	0.9187
5	1.79	1.77	1.85	0.7721
Total Time	18.40	16.92	21.37	0.0942

^{a,b} Values without common superscript in same row are significantly different at p<0.05.

There was no correlation between total time taken to lie down and various measurements (see Table 9.9) either for both breeds combined, or each breed separately. There was also no correlation between these parameters and individual stage times for both breeds or each breed.

Table 9.9 Correlation between total time taken to lie down and various measurements (all sows).

Parameter	r-Value	p-Value
Length of time within system	0.133	0.5388
Height at Shoulders	0.217	0.2978
Breadth at Shoulders	0.244	0.2302
Total Bodyweight	0.043	0.8339
Stage of Gestation	0.069	0.8764

However, there was a strong positive correlation between body length and total time taken to lie down (see Figure 9.3) for both breeds combined.

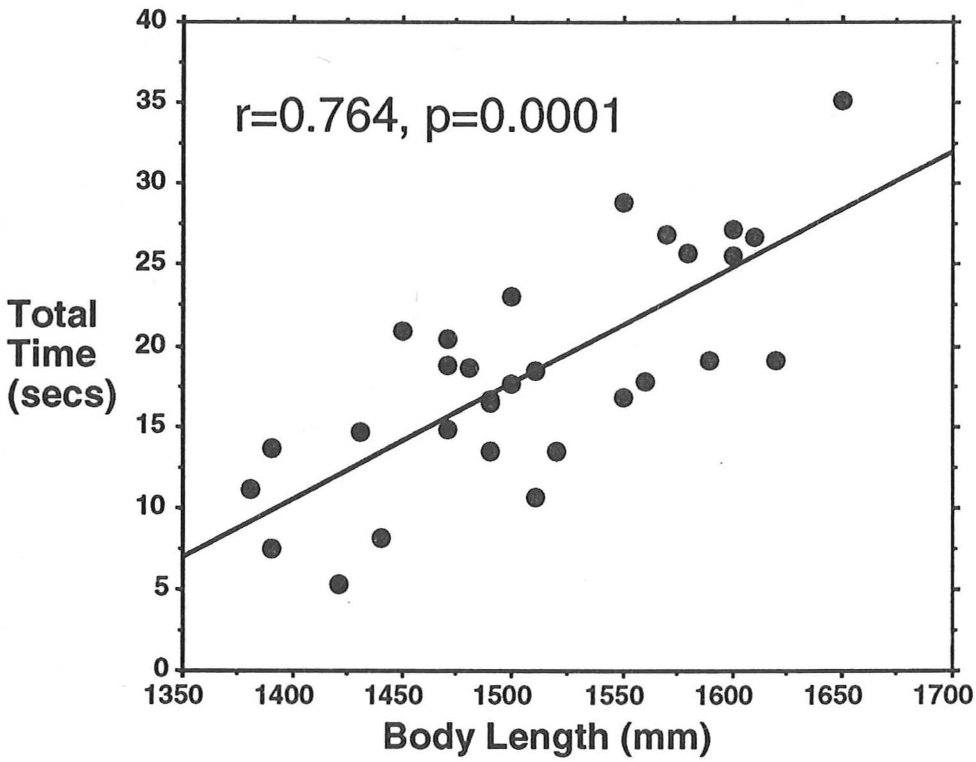


Figure 9.3 Correlation between total time taken to lie down and body length (all sows)

There was also a significant correlation between body length and all stages of the movement except Stage 5 (see Table 9.10).

Table 9.10 Correlation between body length and time to lie down (all sows).

Stage	Average Time	r-Value	p-Value
1	1.667	0.459	0.0108
2	8.402	0.732	0.0001
3	1.426	0.536	0.0023
4	5.101	0.441	0.0147
5	1.795	0.254	0.1751
Total	18.40	0.764	0.0001

When the results were correlated within breeds, there was a stronger correlation between total time taken to lie down and body length for Large White X Landrace sows compared with Large White/Landrace X Hampshire sows (see Figures 9.4 and 9.5).

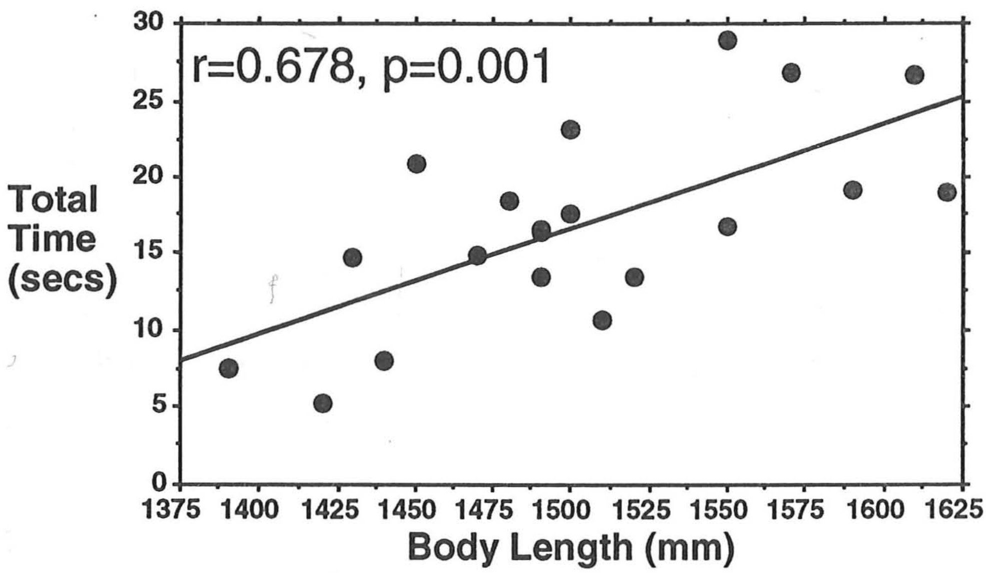


Figure 9.4 Correlation between body length and total time taken to lie down (Large White/Landrace X Hampshire sows).

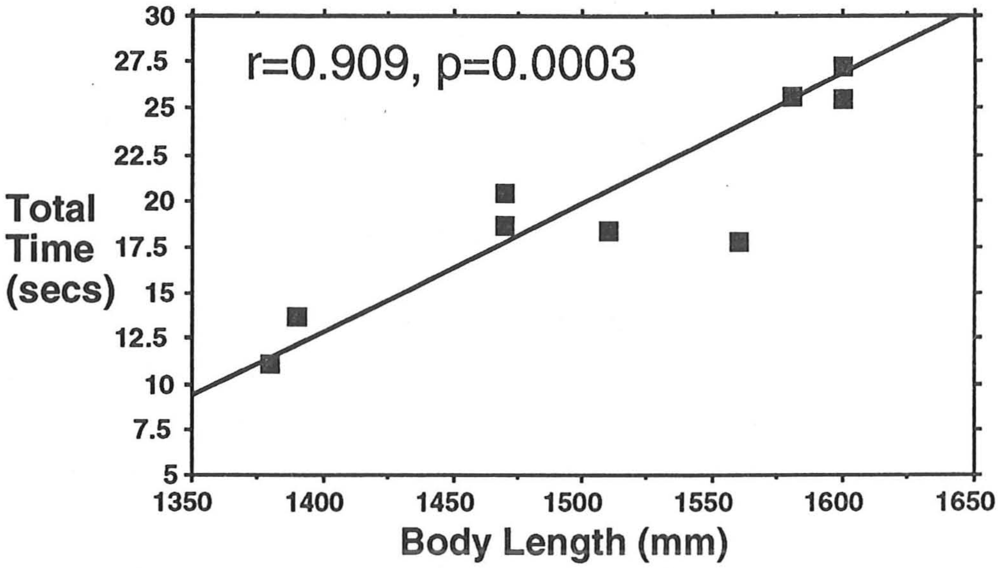


Figure 9.5 Correlation between body length and total time taken to lie down (Large White X Landrace sows).

In terms of r-value, there was also stronger correlation between time and body length for LW x Landrace sows for Stages 2, 3 and 4 (see Table 9.11). However, the sample size was small and not all these correlations were significant. There was no correlation between time and body length for Stage 5 in either breed, although the correlation was higher in Hampshire Cross sows.

Table 9.11 Correlation between time taken to lie down and body length by breed.

Stage Times	LW/Lr X Hampshire		Large White X Landrace	
	r-Value	p-Value	r-Value	p-Value
1	0.457	0.0426	0.443	0.1993
2	0.672	0.0012	0.826	0.0033
3	0.539	0.0143	0.573	0.0833
4	0.443	0.0502	0.450	0.1915
5	0.364	0.1144	0.047	0.8966
Total Time	0.678	0.0010	0.909	0.0003

9.3.3.2 Discussion

The introduction of a Hampshire blood-line on this unit, was to allow the sows to be accommodated outdoors if required, and to allow outdoor rearing of the progeny. Hampshire genes should tend to decrease the body length of the sow, although there was no significant decrease in body length with the number of sows measured in this study. There were also no significant differences in body height and breadth between breeds (see Table 9.7). This is probably because both breeds in this study were from Large White and Landrace genetic stock. However, although there was no significant difference in body dimensions, it is possible that there were differences in other anatomical parameters such as muscular conformation, which may affect lying and standing behaviour.

Sows in this study took an average of 18.4 seconds to lie down. This is comparable with the stall-housed sows in Study 1. When the breeds were compared, there was a tendency for LW x Lr sows to take longer in total to lie down than the LW/Lr x Hampshire sows (see Table 9.8). They also took significantly longer during Stages 2 and 3. These differences cannot be explained in terms of body dimensions, but may be due to differences in muscular conformation.

There was no correlation between time taken to lie down and body height or breadth, length of time within the system, body weight or stage of gestation (see Table 9.9). The last three parameters were considered because they might have an effect on lying down behaviour due to their effects on general mobility. However, it would appear that the effect due to body length "over-rides" any other factor. The results of this study confirm the findings of Study 1, in that total time taken to lie down is strongly correlated with body length for sows housed in confinement (see Figure 9.3). The results also show strong correlation between body length and all stages of movement except stage 5. This reinforces the hypothesis that this stage has no element of muscular control, and that external factors do not influence its duration.

A further breed difference, was the stronger correlation between body length and total time for the LW x Lr sows (see Figures 9.4 and 9.5). This may be a further consequence of the possible differences in muscular conformation. The slight tendency for correlation between body length and duration of stage 5 to be significant in LW/Lr x Hampshire sows, may indicate a greater degree of controllability for sows with shorter back length.

9.3.4 Standing Up

9.3.4.1 Results

The behaviour of standing up was seen to take two forms which differed in duration. The first form (or Type 1) was seen in response to a stimulus, such as a sudden noise or a person entering the building, and the sow would go from lying to standing in a very short period. The second form (or Type 2) was seen during normal posture changes and was spontaneous, i.e. would occur without prior external stimulation. These two types could be clearly distinguished on the basis of the length of time taken pausing during Stage 2. For analysis, the discriminating length of time for Stage 2 was set at a maximum of 2 seconds. Where Stage 2 lasted less than this, the behaviour was categorised as Type 1, and longer than this, the behaviour was categorised as Type 2.

When both Types were compared, there were significant differences in duration of all stages and in total time taken to stand up for all sows (see Table 9.12), and also within each breed separately.

Table 9.12 Time taken for sows to stand up during different Types of standing (both breeds combined).

Stage Time	Type 1	Type 2	p-Value
1	1.356 ^{a}	2.329 ^{b}	0.0001
2	0.452 ^{a}	55.11 ^{b}	0.0001
3	1.024 ^{a}	1.222 ^{b}	0.0124
Total Time	2.832 sec ^{a}	58.662 sec ^{b}	0.0001

^{a,b} Values without common superscript in same row are significantly different at $p<0.05$.

Within Types, there were no significant differences in duration between breeds (see Table 9.13), although there were tendencies for Stages 1 & 2 to take longer for Large White X Landrace sows, during Type 1 standing.

Table 9.13 Time taken for sows to stand up, compared by breed.

Stage Times	TYPE 1			TYPE 2		
	Hampshire	LW x Lr	p-Value	Hampshire	LW x Lr	p-Value
1	1.26	1.59	0.0740	2.46	2.15	0.2455
2	0.35	0.71	0.0867	45.20	68.99	0.3066
3	1.08	0.88	0.1199	1.24	1.20	0.7135
Total	2.69 s	3.18 s	0.2191	48.90 s	72.34 s	0.3134

There was no correlation between duration of standing, regardless of Type, and 1) length of time within system, 2) breadth across shoulders, 3) height at shoulder, 4) bodyweight and 5) stage of gestation, for both breeds combined and within each breed. However, there was a positive correlation between duration of standing and body length, but only with Type 1 standing (see Figure 9.6 and Table 9.14).

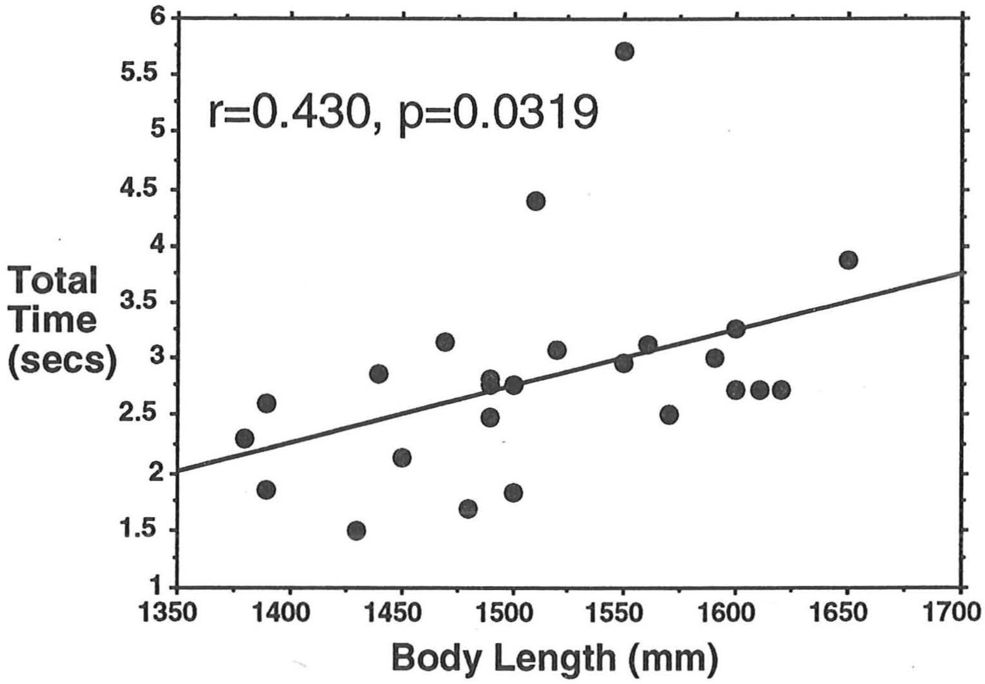


Figure 9.6 Correlation between total time taken to stand up (Type 1) and body length (all sows).

Table 9.14 Correlation between time taken to stand up (Type 1) and body length (all sows).

Stage	r-Value	p-Value
1	0.281	0.1738
2	0.348	0.0884
3	0.338	0.985
Total	0.430	0.0319

When correlation was carried out by breed, again the degree of correlation between total time (Type 1) and body length was greater for Large White x Landrace sows (see Table 9.15), although the sample size was small and the correlation was not significant.

Table 9.15 Correlation between time taken to stand up (Type 1) and body length, by breed.

Stage	LW/Lr x Hampshire		Large White x Landrace	
	r-Value	p-Value	r-Value	p-Value
1	0.427	0.0769	0.033	0.9441
2	0.116	0.6478	0.797	0.0317
3	0.511	0.0301	0.238	0.6071
Total	0.403	0.0969	0.518	0.2341

9.3.4.2 Discussion

The existence of two distinguishable Types of standing is interesting. Baxter and Schwaller (1983) included the recorded duration of standing in a small number of sows, and the results clearly showed differences in the duration of Stage 2, ranging from 0.0 sec to 106.3 sec, but without the behaviour being differentiated into two Types. Baxter (1984) described standing up in detail, but also failed to differentiate between normal standing up, and standing up as an alarm response.

When comparing the two Types, it is interesting to note that all Stages of movement were significantly shorter when the sow stood in response to a stimulus (see Table 9.12). This ability to stand quickly will be especially important in the farrowing house, when the sow may need to stand quickly in response to a piglet squealing if trapped, and also in response to a perceived threat to the litter by a stockman. When breeds are compared (see Table 9.13), there was no significant difference in total duration of Type 1 standing. However, there were tendencies for Stages 1 and 2 to take longer for LW x Lr sows compared with LW/Lr x Hampshire sows, during Type 1 standing. There were no differences between breeds in Stage or total duration, for Type 2 standing.

There was no correlation between duration of standing and body height or breadth, length of time within the system, body weight or stage of gestation. Again, it was considered that the last three factors might have an effect, but similarly, it would appear that the effect of body length is the major factor (see Figure 9.6). There was a significant correlation between body length and total time taken to stand up (Type 1 only). The extent of the restriction of dynamic spatial requirements would appear to be the major factor determining the time taken when standing up quickly. The duration of Type 2 standing was independent of any of the factors examined in this study.

The small sample sizes negated any effect due to breed. The effect of body length on total duration did again appear to be greater for LW x Lr sows (see Table 9.15), but a larger sample size would be required to draw any firm conclusions. However, when Stage times are compared, body length had a greater effect on Stages 1 and 3 for LW/Lr x Hampshire sows than for LW x Lr sows, i.e. the stages involving muscular movement. Standing appears to require a greater muscular effort than lying. These results suggest that there are anatomical differences between breeds, which are affected by body length to a greater degree in Hampshire Cross sows.

9.3.5 Relationships with piglet mortality

9.3.5.1 Results

The results of Section 9.3.4 show that as the body length of the sow increases, the length of time taken to stand up in response to a stimulus and to lie down also increases. This is especially the case for Large White x Landrace sows. However, it is not known whether there is any relationship between the times taken to stand and lie, and piglet mortality. In this section, the percentage of piglets killed by over-lying during the last four farrowings, is compared with standing and lying times and body dimensions.

There was no difference in piglet mortality due to crushing, between breeds. There was no correlation between mortality and total length of time taken to lie down for both breeds combined or for each breed separately (see Table 9.16).

Table 9.16 Correlation between piglet mortality and total time taken to lie down.

Breed	r-Value	p-Value
Both	0.181	0.3391
LW/Lr x Hampshire	0.221	0.3501
LW x Landrace	0.073	0.8412

However, there were a number of positive correlations (significant and tending to significance) between individual stage times and mortality, for both breeds combined and for each breed separately (see Table 9.17).

Table 9.17 Correlation between piglet mortality and lying stage duration.

Breed	Stage	r-Value	p-Value
Both	1	0.404	0.0269
	3	0.437	0.0157
	5	0.377	0.0401
LW/Lr x Hampshire	1	0.447	0.0497
	3	0.466	0.0383
LW x Landrace	3	0.545	0.1031
	5	0.602	0.0657

There was no significant correlation between percentage piglet mortality due to over-lying and duration of either Type of standing, for all sows combined or either breed separately. There was no significant correlation between body height or breadth and piglet mortality for both breeds combined or each breed separately (see Table 9.18).

Table 9.18 Correlation between piglet mortality and body height or breadth.

Breed	Dimension	r-Value	p-Value
Both	Height	0.193	0.3545
LW/Lr x Hampshire	"	0.222	0.3921
LW x Landrace	"	0.212	0.6148
Both	Breadth	0.079	0.7563
LW/Lr x Hampshire	"	0.169	0.1172
LW x Landrace	"	0.138	0.7237

There was a weak correlation between body length and piglet mortality for both breeds combined (see Figure 9.7). When breeds were compared separately, this correlation was seen in Hampshire Cross sows, but not in the Large White x Landrace sows (see Figure 9.8).

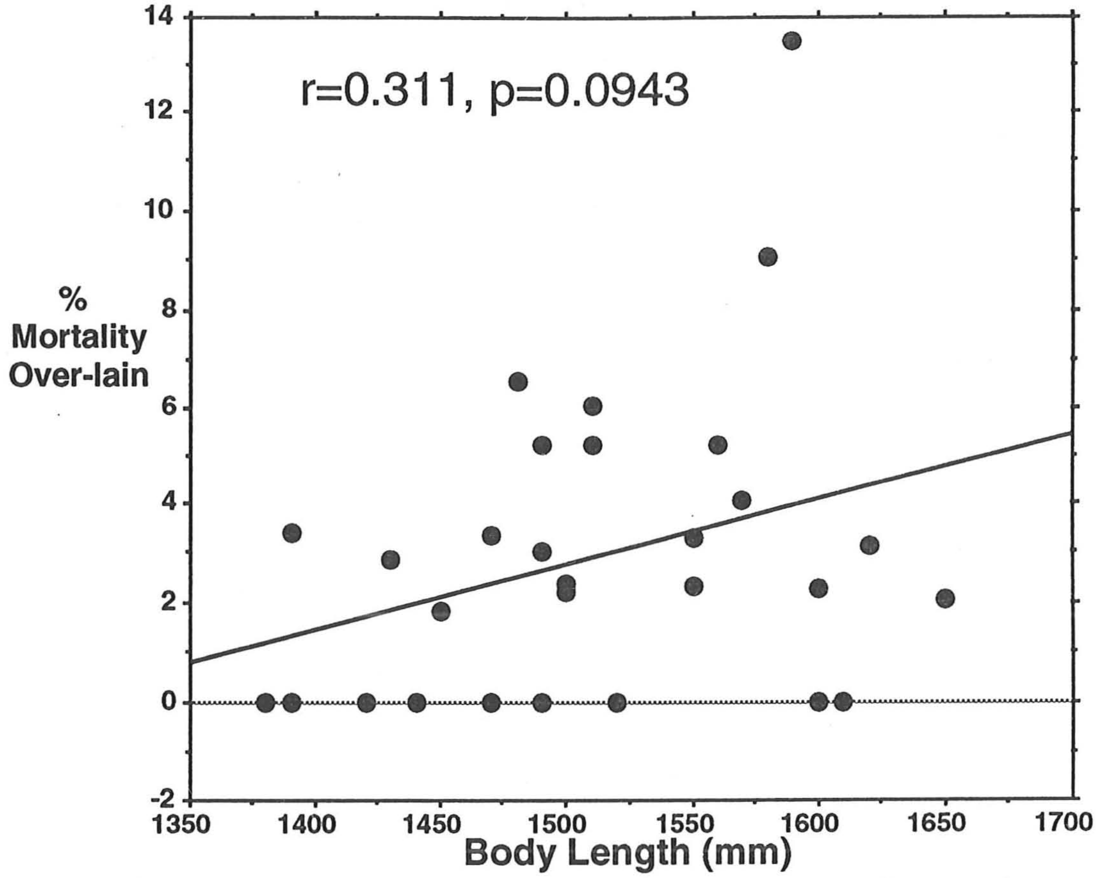


Figure 9.7 Correlation between piglet mortality and body length (all sows).

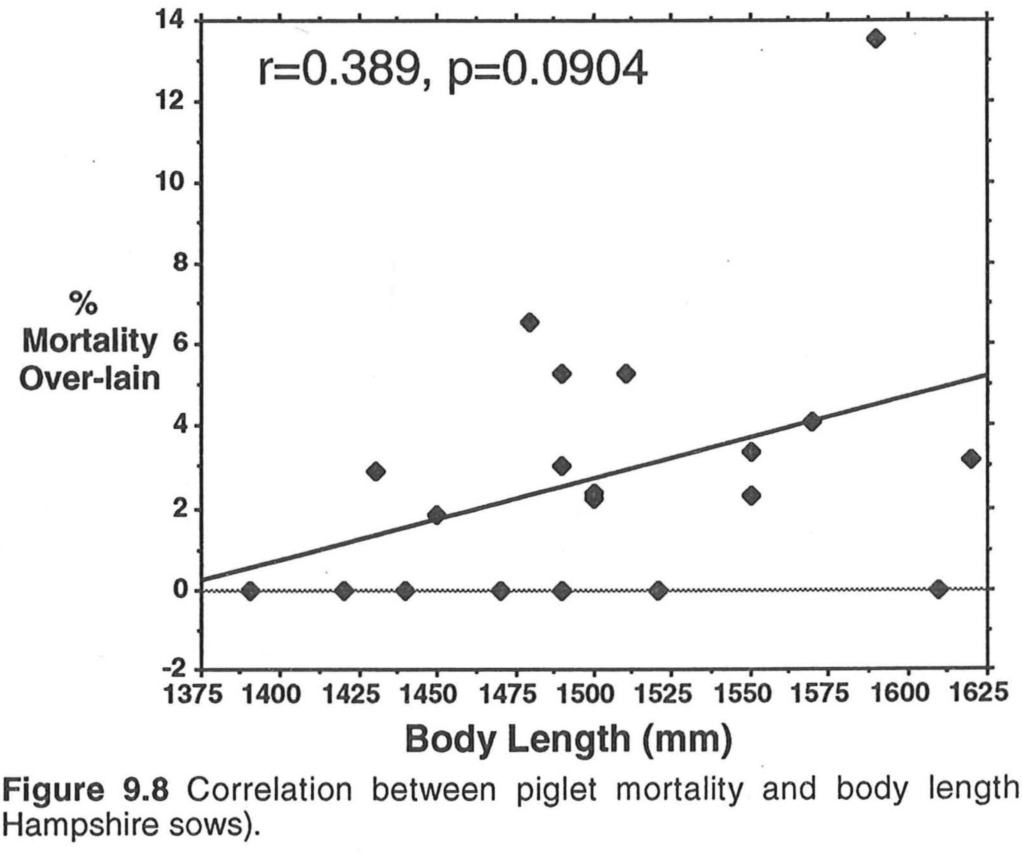


Figure 9.8 Correlation between piglet mortality and body length (LW/Lr x Hampshire sows).

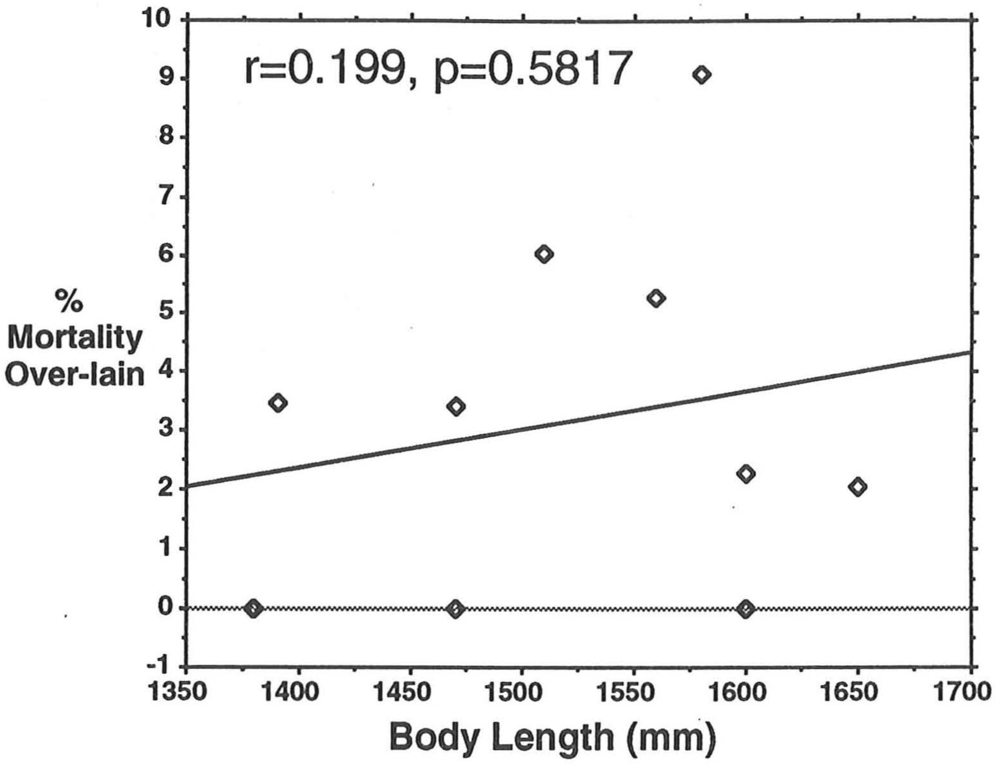


Figure 9.9 Correlation between piglet mortality and body length (LW x Lr sows).

9.3.5.2 Discussion

There was no correlation between total time taken to lie down and the number of piglets killed either for all sows combined or each breed (see Table 9.16). Likewise, there was no correlation between duration of standing of either Type, sow height or sow breadth (see Table 9.17) and number of piglets killed, either for all sows combined or each breed.

However, there was a significant correlation between duration of Stages 1, 3 and 5 and the number of piglets killed by crushing (see Table 9.17), and a tendency for the correlation between body length and number of piglets killed to be significant (see Figure 9.7), for both breeds combined. In terms of breed, there was a significant correlation between Stages 1 and 3 and mortality, and a tendency for the correlation between body length and mortality to be significant, in LW/Lr x Hampshire sows. For the LW x Lr sows, there was only a tendency for the correlation between duration of Stages 3 and 5 and mortality to be significant, and no significant correlation between body length and piglet mortality.

Within a restricted farrowing environment, such as a crate, it is possible that a longer duration of Stages 1, 3 and 5 will increase the number of piglets killed by crushing. Sows with shorter bodies will take less time carrying out Stages 1 and 3, and thus total body length will influence the number of piglets killed by crushing. However, Stage 5 is independent of body length in LW x Lr sows, and thus decreasing body length will not decrease the number of piglets killed at this most critical stage. Therefore, body length does not correlate with piglet mortality for these sows (see Figure 9.9). For LW/Lr x Hampshire sows, there is a tendency for the correlation between body length and duration of Stage 5 (see Table 9.11) to be significant, and thus, decreasing body length can lead to an overall decrease in mortality.

9.4 Study Three

An investigation of the effect of farrowing crates on lying and standing behaviour of loose-housed sows

9.4.1 Introduction

A great deal of research has attempted to determine the factors affecting piglet mortality, but so far, percentage mortality has not decreased much below 11-12%. Mortality can be affected by a range of factors, such as birthweight (Spicer et al, 1986), litter size (English & Smith, 1975) and sow parity (Bäckström, 1973), however, the majority of studies appear to focus on the physical farrowing environment (e.g. Curtis et al, 1989, Cronin & Smith, 1992, Vermeer et al, 1993). The majority of studies have neglected the input from the sow in terms of sheer physical presence, and her behaviour, both normal and maternal. Only a few have attempted to link lying and standing behaviour with piglet deaths (Blackshaw & Hagelsø, 1990, Fraser, 1990). Although free-ranging sows crush very few piglets (Algers, pers.comm.), commercial systems all confer behavioural or physical constraints to a greater or lesser degree. Therefore, it is possible that modification of the external environment will do little to reduce crushing deaths, without some form of modification of the sows entering a farrowing system.

So far, lying and standing has been investigated only in dry sow systems, where the effects of confinement on sow movements has been studied. With approaching legislation, the majority of commercial producers will continue to farrow their sows in crates, whilst gestating them in an open system. Thus, it is important to determine the effects of short term confinement on lying and standing behaviour. It is also necessary to investigate whether the results of the previous studies linking piglet mortality to stage duration during lying in a confined dry sow system, are applicable to a confined farrowing system.

The objectives of this study were to determine the effects of confinement in farrowing crates on the duration of lying down in sows which had previously gestated in an open environment. It was also hoped to determine whether the sow altered her lying and standing behaviour when piglets were present and whether the duration of these behaviours had any effect on piglet mortality.

9.4.2 Methods

The study was carried out on 16 Large White X Landrace sows of similar age, parity and genetic stock, from the large group system, at the Animal Welfare Group's pig unit. The time taken to lie down within the dry sow system had been previously recorded during Study 1 (see Section 9.2). All sows had been measured to determine body length from crown to tailhead, height to the point of shoulder and breadth across shoulders.

The sows were moved to the farrowing crate house five days prior to predicted farrowing date, and were video-recorded for 4 hours per day up to farrowing. After parturition, they were recorded for 4 hours on days +7 and +10. From the video data, the total length of time taken to lie down and stand up were determined, together with individual stage duration. The durations were then correlated with sow body dimensions and also the average piglet mortality due to crushing over the last four farrowings in crates.

9.4.3 Results

During the first few days within the farrowing crate, the sows took significantly longer to lie down compared with the same behaviour within the dry sow system (see Figure 9.10). However, after parturition (approximately 10-15 days after entry), the sows were slightly quicker lying down, but were still significantly slower than when lying down next to the wall in the dry sow system.

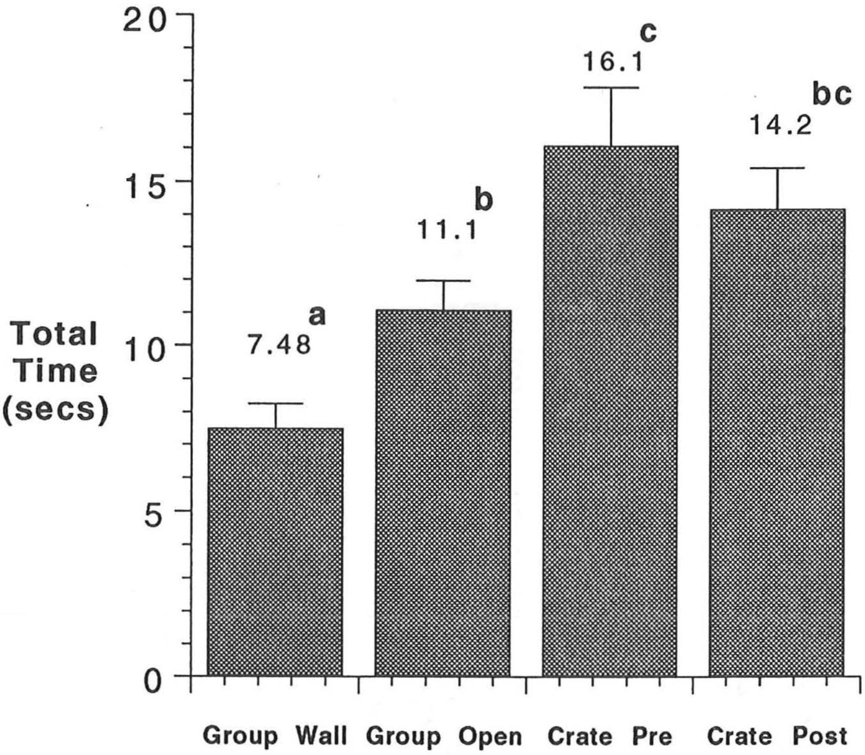


Figure 9.10 Mean total time (+ s.e.) taken to lie down by sows in a group system with and without the aid of a wall, and also in farrowing crates before and after farrowing. a,b,c Values without common superscript are significantly different at p<0.05.

The major cause of this increased time taken to lie down was the extended pause at Stage 2 (see Table 9.19). Before parturition, the pause at Stage 4 was also significantly longer for sows in the crates. However, this difference was no longer present when the sows were recorded again, after parturition. Sows in the crates completed Stage 1 quicker than in the dry sow system.

Table 9.19 Total and stage times taken to lie down by sows in a group system with and without the aid of a wall, and also in farrowing crates before and after farrowing.

Stage	Grp Wall	Grp Open	Crate Pre	Crate Post	p-Value
1	1.74 ^{a}	2.22 ^{b}	1.26 ^{c}	1.20 ^{c}	0.0001
2	0.93 ^{a}	3.09 ^{b}	7.57 ^{c}	7.41 ^{c}	0.0001
3	1.24	1.18	1.29	1.16	0.6710
4	2.06 ^{a}	2.61 ^{a}	4.43 ^{b}	2.82 ^{ab}	0.0610
5	1.53 ^{a}	2.04 ^{b}	1.54 ^{a}	1.61 ^{ab}	0.0688
Total	7.48 ^{a}	11.07 ^{b}	16.09 ^{c}	14.20 ^{bc}	0.0001

^{a,b,c} Values without common superscript in same row are significantly different at p<0.05.

There was no difference in duration of Type 1 standing, before or after farrowing. However, the duration of Type 2 standing was greater before parturition compared with after parturition.

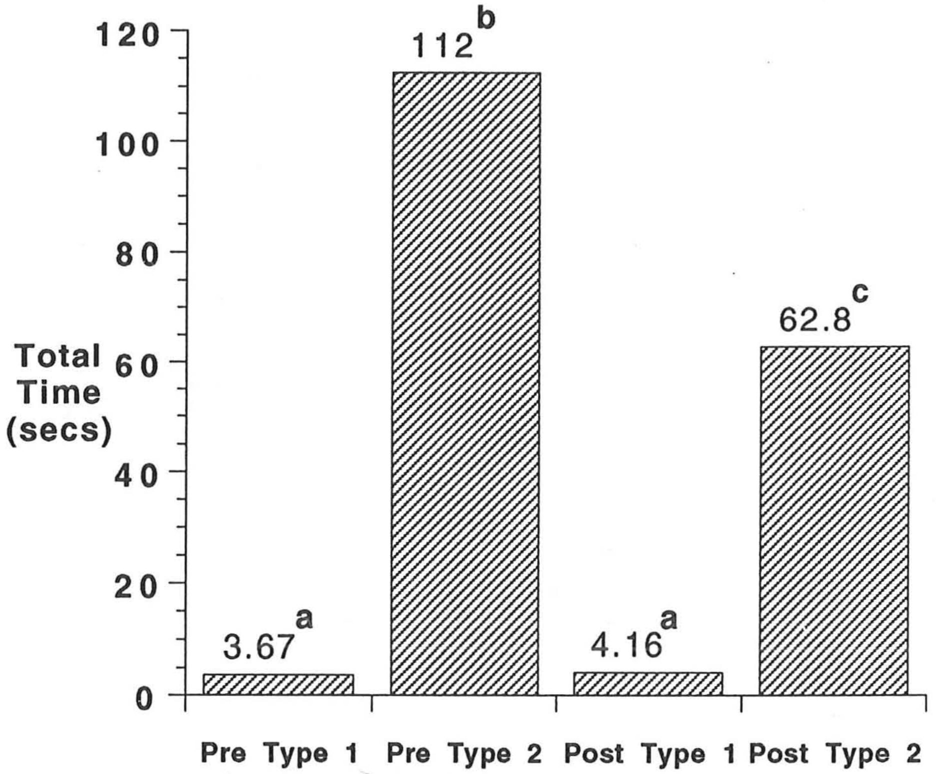


Figure 9.11 Total time taken to carry out both types of standing up before and after farrowing. a,b,c Values without common superscript in rows are significantly different at $p<0.05$.

All Stages of Type 2 standing took longer than the corresponding Stages of Type 1 standing (see Table 9.20). The difference in duration between Type 2 standing before and after farrowing was due to an extended pause during Stage 2.

Table 9.20 Total and stage times taken to carry out both types of standing up, by sows in farrowing crates before and after farrowing.

Stage	Pre Type 1	Pre Type 2	Post Type 1	Post Type 2	p Value
1	1.40 [a]	2.09 [b]	1.44 [a]	2.33 [b]	0.0001
2	1.10 [a]	108.9 [b]	1.58 [a]	58.48 [c]	0.0001
3	1.17 [a]	1.53 [b]	1.13 [a]	1.99 [b]	0.0011
Total	3.67 [a]	112.5 [b]	4.16 [a]	62.81 [c]	0.0001

a,b,c Values without common superscript in same row are significantly different at $p<0.001$.

There was no significant correlation between the length of time taken to stand up (total or individual Stage) and piglet mortality, sow length, height or breadth with respect to Type of standing, or whether timed before or after farrowing. Likewise, there was no correlation between length of time taken to lie down (total or individual Stage) and piglet mortality, sow length, height or breadth, with respect to whether timed before or after farrowing.

However, there was correlation between all three sow dimensions and average percentage of piglets killed by crushing (see Figures 9.12, 9.13 and 9.14). There was no correlation between sow weights and piglets crushed.

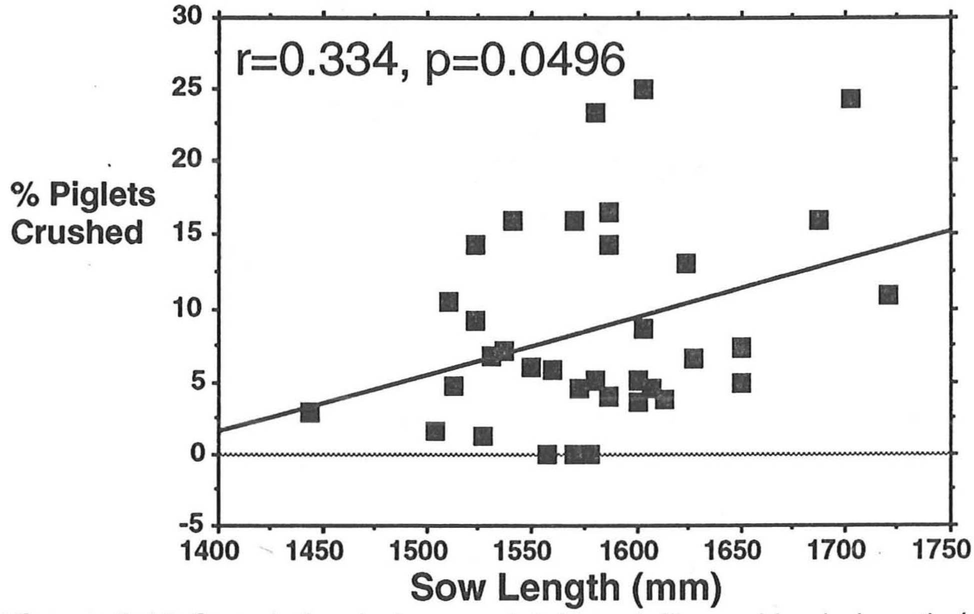


Figure 9.12 Correlation between piglet mortality and body length (all large group sows) in crates.

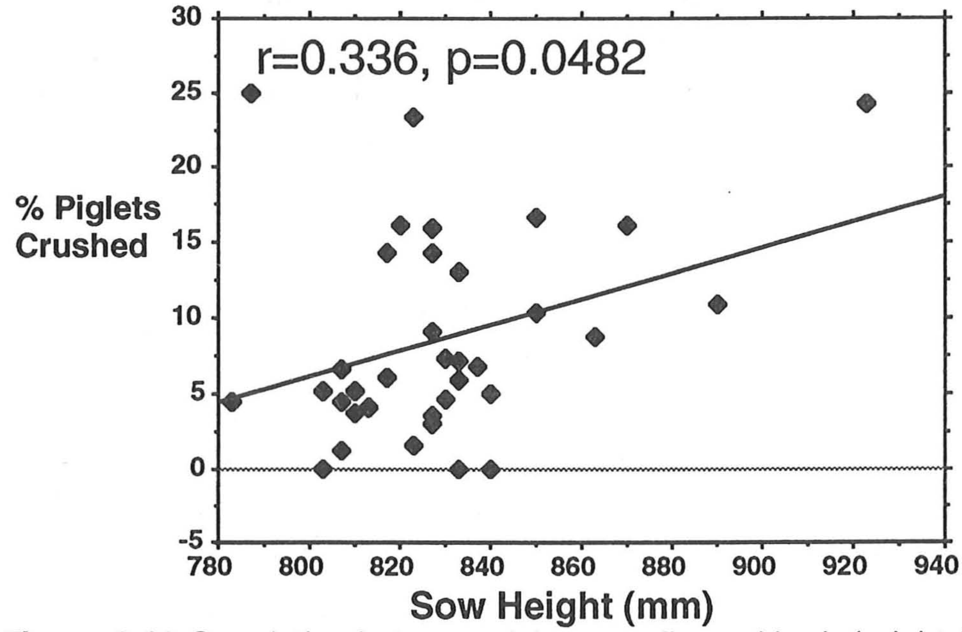


Figure 9.13 Correlation between piglet mortality and body height (all large group sows) in crates.

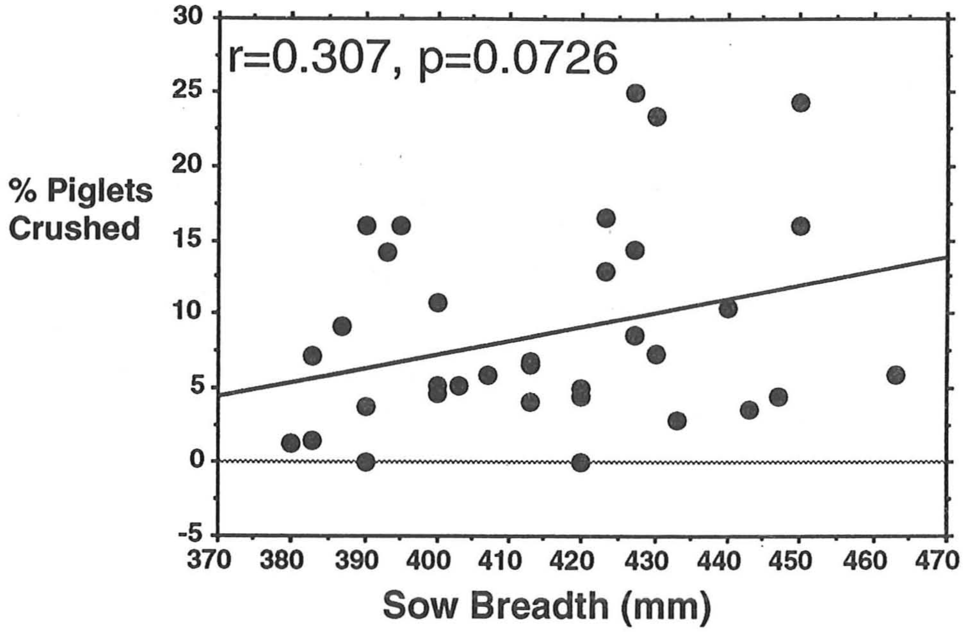


Figure 9.14 Correlation between piglet mortality and body breadth (all large group sows) in crates.

9.4.4 Discussion

The results demonstrate that when previously loose-housed sows are housed in confinement, they take significantly longer to lie down (see Figure 9.10) which is caused by these sows pausing for longer during the lying down behaviour. This may indicate a degree of discomfort caused by restriction of their dynamic spatial requirement. There appeared to be little in the way of accommodation to confinement, although the pausing Stage 4 did tend to decrease in duration when piglets were present. This may be a response of the sow to the presence of piglets walking in her vicinity, just before the irreversible final Stage of lying. There was also a significantly shorter pausing Stage during Type 2 standing after farrowing had occurred. Again, this could decrease the chance of piglets straying into the danger area during the final Stage of standing, when slipping is most likely.

In this study, there was no correlation between Stage or total times taken to lie down and body length. This may be due to the increased muscular fitness seen in these group-housed sows compared with stall-housed sows (see Chapter 8). Any dynamic spatial difficulties may be partially compensated for by greater mobility and muscular strength. There was also no correlation between lying times and piglet mortality. This may be due mainly to the timing of recording. The majority of deaths due to crushing are very early on in neonatal life. Thus, there may be a more discernible alteration of lying and standing behaviour in the first few days after birth, and piglet crushing may correlate with lying and standing times only during this critical period.

Despite the above results, there was confirmation of the results of study 2, with respect to the correlation between sow length and mortality due to crushing. In this study, there was also correlation between sow height and breadth and piglet mortality, but not with sow weight. This may support the problems seen by Baxter & Schwaller (1983) and Curtis et al (1989) in that commercial crates do not allow sufficient dynamic space for the sow to stand and lie unhindered. Hence, there may be an alteration in the way in which these sows lie, rather than in the amount of time they take to do so, that renders the litter more susceptible to crushing. Investigation using kinetic analysis similar to that demonstrated on cattle by Sato & Hasegawa (1993) may elucidate other differences in this behaviour.

9.5 Overall discussion

There is no doubt that piglet mortality remains a large problem in commercial pig production, and that attempts to reduce this figure by minor modifications of the farrowing system have had little effect. It is my opinion that the one major factor behind piglet mortality as it stands at present, is that of genetic selection. Over the last few decades, the sow has been genetically selected purely in terms of meat production. She has been bred to give piglets that grow fast, have elongated bodies for bacon production, and provide lean carcasses. She is also expected to produce consistently large litters. These factors have resulted in a sow that is "anatomically challenged". As I stated earlier, it is unreasonable to expect the modern sow kept on a rigid floor not to crush a proportion of her litter. She no longer has the control of her body during lying and standing, especially if she has been kept in confinement without the benefit of exercise to maintain what muscle she has.

The results of this, and the previous chapter, highlight the anatomical inadequacies of the modern commercial sow. If kept in confinement, she has poor muscular conformation and weak bones. Her lying and standing is difficult, and this difficulty increases with body length. If kept in a loose system, her muscular conformation is better and her bones stronger, but she still cannot fully control herself when lying down. Transferring these sows to a commercial crate results in high piglet mortality, because she has insufficient space to move, and still cannot control her lying down. The longer she is, the more piglets she will kill by crushing.

How does she fare in a loose farrowing system. Unfortunately, in those which have been studied here, she fares no better. The improvement in her welfare may be to the detriment of her litter's welfare. It has been reported that sows in a pig park are well controlled when lying and do not crush piglets (Algers, pers. comm.). Jensen (pers comm) has noted that these sows will alert piglets of their intentions to lie down, by carrying out a period of rooting behaviour prior to the action, accompanied by vocalisations. This rooting behaviour allows the sow to locate any piglets in the lying area, and has also been reported by Blackshaw & Hagelsø (1990), in sows lactating in open straw pens. In confinement, the sow will be unable to turn round and locate piglets in the danger area, and thus may crush her piglets more readily. In a loose system, she has the opportunity to interact with her litter and prevent these deaths, but somehow this does not happen.

There may be two possible explanations for this, both connected with the excessive meat-oriented genetic selection. Firstly, maternal behaviour as a quality has been neglected. There may be greater opportunity to carry out maternal behaviour in a loose farrowing system, but the motivation to do so appears fairly weak. Also, the problem of body length appears again. When body length is correlated with percentage of piglets killed by crushing in farrowing pens, there is a strong positive correlation (see Figure 9.15).

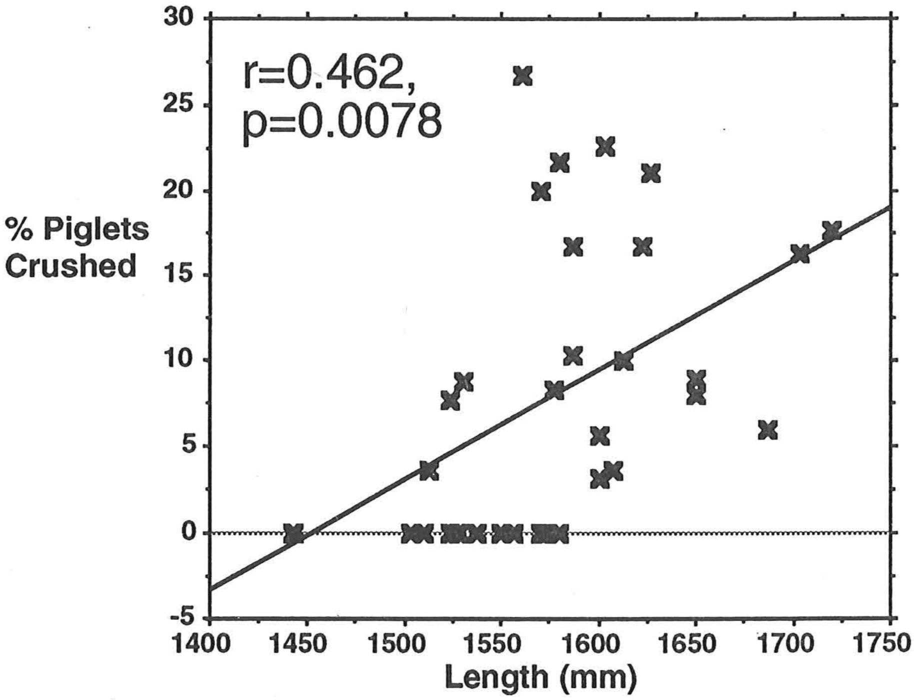


Figure 9.15 Correlation between piglet mortality and body length (large group sows) in pens.

Thus, body length is seen as a major factor influencing the number of piglets killed by crushing. There is an effect on sows from confined and group dry sow housing systems, and also an effect on sows farrowing in crates and loose pens.

CHAPTER 10

General discussion and conclusions

10.1 Introduction

The welfare of an individual animal is its state as regards its attempts to cope with its environment (Broom 1986a). The scientific assessment of how an individual is coping, and thus its welfare, requires an amalgam of different measures such as production, behaviour, physiology, immunology and pathology. A variety of potential welfare indicators have been examined in the experimental chapters of this thesis, and a detailed discussion of the results obtained within each study, has been included within the relevant chapter or chapters. In this final chapter, all the information and results contained within the thesis will be tied together, in order to give an overall indication of how the welfare of the breeding sow is affected by the housing systems in which she is kept.

The studies described in this thesis have been undertaken to assess the welfare of the breeding sow both within the dry sow environment and within the farrowing environment. In particular, the studies have focused on assessing the influence of previous experience of open or confined dry sow housing conditions on the responses of the sow when she is housed in an open or confined farrowing system. As the UK pig industry moves away from confinement during gestation towards group housing, and yet retains farrowing crates, knowledge of any influence will become increasingly important. Also, the continued use of farrowing crates is likely to be the next area of consideration in terms of acceptable welfare standards, and thus a thorough understanding of the welfare of the sow and her litter, in crates and in alternative farrowing systems, is required to ensure that any legislative decision is the correct one.

10.2 Review of results

In Chapter 5, it was shown that production figures for all sows deteriorated greatly after the sixth parity. Litter size decreased and mortality increased, resulting in a sharp decline in the number of piglets weaned per litter. Stall-housed sows gave birth to the most piglets per sow per year. They had the largest total litter size and number of piglets born alive, the heaviest total litter weight, the shortest weaning to conception interval and the least returns to service. However, they also gave birth to piglets with the lowest individual birth weight, and had the highest piglet mortality. Overall, piglet mortality was higher in farrowing pens than in crates, and group-housed sows took longer to come back into œstrus after farrowing in pens, perhaps due to the disturbance by weaning of a stronger mother-offspring bond. Large group sows had a significantly larger number of returns to service after farrowing in crates.

The results of Chapter 6 demonstrated that all sows appeared to adapt well following a move to the farrowing house and all showed a significant increase in the number of posture changes, reaching a maximum during the 24 hours immediately prior to parturition. However, this increase was greatest in those sows in farrowing crates, which had previously gestated in an open environment, perhaps indicating an increased amount of frustrated maternal behaviour for these sows.

In Chapter 7, it was shown that basal heart rate is correlated positively with stage of gestation, which will thus influence the absolute heart rate during various behaviours. The heart rate of sows was influenced by posture and by behaviours such as rooting, drinking and feeding. Sows housed long-term in stalls had a significantly higher basal heart rate and heart rate response to feeding than group-housed sows, perhaps indicating decreased cardiovascular fitness and an increased sympathetic nervous response to important stimuli such as food.

Also in Chapter 7, it was demonstrated that group-housed sows housed in farrowing crates had a higher heart rate response to the suckling event than stall-housed sows farrowing in crates. This may be due to a general unresponsiveness in stalled sows or to high reactivity to the suckling event in group-housed sows because of distress at physical restriction and frustration of mother-infant interaction. Within the farrowing crates, there was no difference in heart rate response to feeding between stall and group sows, which may indicate an increased sympathetic nervous stimulation in response to short-term confinement.

The heart rate of sows increased during agonistic social interactions regardless of whether the interaction involved physical contact or not, and whether the interaction was won or lost. However, the change in heart rate was greater for sows involved in a physical interaction, and greatest for sows which lost this type of interaction. This indicates the poor welfare of subordinate sows which lose such encounters frequently, especially in systems where group-feeding is employed.

In Chapter 8, it was shown that long-term confinement affected muscular conformation, resulting in decreased proportional weight of certain locomotory muscles and hence, decreased muscular strength when compared with group-housed sows. This causes some stall-housed sows to have difficulty carrying out the movements necessary for posture changes, and leads to an increased susceptibility to lameness by altering joint angles and increasing strain on particular muscles or ligaments. Stall-housed sows also had significantly weaker bones than group-housed sows probably due to lack of exercise and a decreased dynamic loading. This may also increase the susceptibility of stall-housed sows to lameness due to bone damage or fracture.

The results in Chapter 9 demonstrate that, when lying down, stall-housed sows took significantly longer than group-housed sows and thus had greater difficulty. The time taken for stall sows to lie down was positively correlated with body length, with the correlation being stronger for Large White x Landrace sows than for cross-bred sows. For group-housed sows lying down in the open, the time taken was correlated positively with the proportional weight of certain locomotory muscles. Spatial restriction when lying resulted in the loss of muscular control. When stall sows stood up quickly, there was a strong positive correlation between length of time taken and body length.

The number of piglets killed by crushing was not positively correlated with the total time taken to lie down or stand up, either in the dry sow environment or the farrowing environment. However, there was a positive correlation between body length and crushing mortality for stall-housed sows farrowing in crates, which was stronger for cross-bred sows. Group-housed sows placed into farrowing crates took longer to lie down than in the dry sow system, and there was also a positive correlation between body length, height, breadth and crushing mortality for group-housed sows farrowing in crates. This indicates the degree of dynamic spatial restriction imposed by crates.

There was also a positive correlation between body length and crushing mortality for group-housed sows farrowing in pens. This indicates that the sow can have problems controlling movements, even in the presence of piglets.

10.3 General discussion

All three dry sow systems, and both farrowing systems, compared in these studies have advantages and disadvantages, in terms of welfare, husbandry and production. To some degree, the recommendation of one system above the other two will vary depending on the relative importance placed upon each of these factors. The primary aim of this thesis was to assess and compare the welfare of sows within different environments, and thus, any recommendations are made with welfare as a major consideration. However, the discussion will also address the other factors and indicate the relative merits of each system.

10.3.1 The dry sow environment

A large number of studies have demonstrated that the welfare of sows kept in confinement during gestation, whether in stalls or in tethers, is poor when compared with loose-housed sows. Confined gilts have taken longer to reach first œstrus (Jensen et al, 1970, Mavrogenis & Robinson, 1976) and stall-housed sows longer to return to œstrus after weaning compared with group-housed sows (Sommer, 1979, Sommer et al, 1982, Hemsworth et al, 1982), although this may be partly due to the difficulties of recognising œstrus in confined animals. Sows housed individually may also return to service more frequently (Fahmy & Dufour, 1976). In general, these results do not agree with those reported in Chapter 5. In this study, stall-housed sows were quicker returning to œstrus, and also had the fewest returns to service compared with sows housed in both group systems. The latter result has been reported in group systems where inter-sow aggression is a problem (Maclean, 1969, Hansen & Vestergaard, 1984).

The production advantages of stall-housed sows over group-housed sows within this study, also includes significantly larger litters with more born alive and fewer born dead. The differences between systems may best be explained in terms of timing of mixing back into the herd after service, and the extent of aggression. Ideally, the sows are held in the service pens for about three weeks after service, to ensure implantation of embryos occurs. However, if there is insufficient space to accommodate newly weaned sows, the served sows are reintroduced before implantation may have fully taken place. A further factor for early reintroduction of sows into the large group, is the need to reintroduce sows in groups of five.

Within the stall house and the small group house, inter-sow aggression does not occur on the same scale as within the large group system, and thus early reintroduction does not pose such great problems. The incidence of returns to service is slightly higher in the small groups compared with the stalls, and litter size is smaller which may indicate a greater degree of stress-induced embryo loss. However, the number of returns to service is high in the large group system, where aggression involving physical contact is most prevalent. The results presented in Chapter 7 have demonstrated the extent to which agonistic interactions raise heart rate. Although levels of aggression may be high in the stalls, the physical component is severely limited and thus the stress response of the receiver is not likely to be as high as in some individuals in the loose house environments. In the system which appears to have the highest incidence of physical inter-sow aggression, the incidence of total embryo loss is greatest.

In terms of production potential, these figures, together with the short weaning to conception interval, could greatly increase the number of piglets produced per sow per year compared with group-housed sows. However, these advantages are somewhat balanced by higher piglet mortality for stall-housed sows, which results in there being no significant difference in the number of piglets weaned per litter, between dry sow systems. It has been shown in this thesis that stall sows have a lower degree of cardiovascular fitness (see Chapter 7) and muscular fitness (see Chapter 8), and that they took significantly longer to lie down than group-housed sows, in the dry sow environment. The lying behaviour of these sows was not studied within the farrowing environment, but there was a link between piglet mortality and body length (see Chapter 9).

The results in Chapter 9 demonstrate that all sows, regardless of dry sow system, have difficulty in the control of lying down, and that any control becomes more difficult as the body length of the sow increases. Sows kept in confinement have no opportunity to exercise, and thus find it particularly difficult to control lying because they lack muscular strength. The increased piglet mortality may be due in part to a greater degree of crushing during lying, but may also be a result of the higher number of lighter piglets. Stall-housed sows gave birth to piglets with a lower average birthweight than group-housed sows. This results in more piglets being born weighing around 1kg, which is thought to be critical in terms of survivability.

When given the opportunity, pigs have a very elaborate behavioural repertoire (Jensen, 1986, 1988, Jensen & Redbo, 1987, Jensen et al, 1987). Commercial systems impose constraints on this repertoire to a lesser or greater degree depending on the type of system used, and will therefore alter or modify behaviour away from the "normal". A large number of studies have demonstrated a high frequency of stereotypic behaviours in stalled and tethered sows (e.g. Jensen, 1981, Cronin & Wiepkema, 1984, Broom & Potter, 1984). Feed restriction alone can lead to the development of stereotypic behaviour (Terlouw et al, 1991, Terlouw & Lawrence, 1993) but the highest levels of stereotypic behaviour are seen in sows that are fed a restricted diet and are confined next to other sows (Mendl et al, 1993). It has been demonstrated that the influence of neighbours (Appleby et al, 1989) is a major factor in manifestation of stereotypies.

Confined sows also appear to become less responsive to most stimuli, than group-housed sows (Dantzer et al, 1986, Broom, 1986b, 1987). However, when food was used as the stimulus, it has been reported that there was no difference in responsiveness between systems. The results reported in Chapter 7, have shown the importance of the feeding event for stall-housed sows, in terms of a greater heart rate response at feeding than group-housed sows. A similar result has been reported by Schouten et al (1991). There is no doubt that feeding is a very important event for the sow regardless of system, and will remain so as long as restrictive feeding is practised. The majority of daily inter-sow aggression occurs during feeding. The results of aggression on heart rate and subsequent welfare at mixing have already been discussed. However, in a group system, once the social hierarchy has been re-established, aggression continues especially at feeding.

The two group systems compared in this thesis both employed individual feeding to some degree. In the small groups, the sows were shut into feeding stalls and could therefore be fed an individual amount, and could eat without fear of displacement, although the design of the stalls did permit attempted aggression. The large group system employed an Electronic Sow Feeder, which again allowed the feeding of an individual amount which could be eaten without the sow being subjected to aggression. In order to enter the feeding station, the sows did have to overcome aggression from more dominant sows at the feeder entrance, but at least the sow could choose when to feed, and did not have to compete with other sows to gain sufficient ration.

Simultaneous feeding has been deemed beneficial (Edwards, 1985, Whittemore, 1993), but the problem of aggression remains very real. Group systems employing trickle feeders whereby feed is delivered simultaneously but very slowly, supposedly ensuring sows remain at one feeder, are currently undergoing trials, and the results will be interesting to see. Dump feeding is also being evaluated, but the problems associated with floor feeding of this kind have already been reported (Csermely & Wood-Gush, 1986, Edwards et al, 1993). Both these systems have the disadvantage of the stockman not being able to control each sow's ration. Within any group of sows, dominant sows will displace subordinate sows, and thus with floor feeding, there is a great risk of subordinate sows not eating enough. Removal of dominant sows will result in others taking their place, and will not alleviate the problem.

Differences between systems using physiological indicators have also been reported. Confined sows have been shown to have a higher baseline concentration of cortisol, and a greater maximal response to ACTH challenge than those kept in a group system (Barnett et al, 1984, Hemsworth et al, 1987) although others have reported no difference (McGlone et al, 1993). Differences in heart rate responses have already been discussed.

Confined sows have been reported as being more prone to urinary diseases than loose-housed sows (Madec, 1984, 1985, Tillon & Madec, 1984). This may be as a consequence of altered lying, drinking and eliminative behaviours, but may also be due to increased susceptibility caused by stress-induced immunosuppression. Nicholson et al (1993) found higher Natural Killer cell activity in stall sows and subordinate group sows compared with dominant group sows. Lameness has also been reported as being more frequent in confined sows (Bäckström, 1973, Tillon & Madec, 1984). The results from Chapter 8 demonstrated that stall-housed sows have smaller and hence, weaker locomotory muscles than group-housed sows, and weaker leg bones. These differences may help to explain the higher incidence of lameness seen in confined sows. Lameness is the second largest cause of the early culling of breeding sows, and within a large-scale commercial company, it has been shown to range from 24% of all culls for stall sows, through 10-15% for indoor group systems to 3.4% for outdoor systems.

In conclusion, from a welfare point of view, the trend away from confinement towards group housing is a good thing. However, although the change may do away with a number of welfare concerns, it also introduces new ones. More needs to be done to confront the problems associated with mixing and feeding, before any particular group system can be recommended above others.

10.3.2 The farrowing environment

The welfare of sows farrowing in confinement has likewise been subjected to close examination. However, when farrowing systems are compared, any assessment should also take into account the welfare of the litter. In terms of production, the success or otherwise of a farrowing system is usually expressed by the percentage piglet mortality. The majority of studies, including this one, have found a higher piglet mortality in open systems compared with conventional crates (e.g. Aherne, 1982, Cronin & Smith, 1992). However, others have found no advantage either way (Gustafsson, 1982, Collins et al, 1987, Arey et al, 1992).

A reason for the high mortality figures overall, may be the physical size of the sow and the effects of the dry sow system on lying behaviour, rather than any particular feature of the farrowing system (see Chapter 9). The modern sow has difficulty in controlling lying down, particularly if she has been kept in confinement during gestation. Therefore, the risk of piglets being killed by crushing in any farrowing system will be high. There may also be inadequate motivation to carry out maternal behaviour. As farrowing systems move away from confinement, there will be a greater dependence on mothering ability. The development of some communal farrowing systems which allow the sow some time away from her litter, has highlighted maternal inadequacy and has led to litters being deserted for long periods of time (Rudd et al, 1993). This has resulted in unacceptably high mortality figures, due to piglet starvation.

In terms of the sow's welfare, crates allow no freedom for the sow to carry out her preferred behaviour. Work by Jensen (1988) has detailed the pre- and post-farrowing behaviour of free-ranging sows, and has highlighted the degree of restriction imposed by all farrowing systems currently in commercial use. The importance of, and the motivation for, nest-building has been reported (Jensen, 1989, Arey et al, 1991, Zanella & Zanella, 1993), and it is obvious that crates fall far short of satisfying this need. In Chapter 6, it was reported that sows housed in crates changed posture more often than sows housed in pens, during the 24 hours immediately prior to parturition. This was interpreted as a form of frustration behaviour caused by the inability to nest-build and has been reported in less detail elsewhere (Hansen & Curtis, 1981, Heckt et al, 1988, Vestergaard & Hansen, 1984). The duration of farrowing may also be longer for crated sows, with an increase in the number of piglets stillborn (Bäckström, 1973, Gustafsson, 1982).

The sow's behaviour during lactation is also greatly affected by the farrowing accommodation. Free-ranging sows opt to spend time away from the litter (Jensen, 1988) after the first few days during which the mother-offspring bond is formed and reinforced. Crates afford little opportunity for mother-piglet social interaction to occur, and can influence the duration of suckling behaviour by both sow and piglets (Cronin & Smith, 1992a). Sow-piglet communication is also very important during lying, because it could prevent crushing. It has been reported that the sow will communicate her intentions to lie down, both vocally and physically (Blackshaw & Hagelsø, 1990). However, if the behaviour of lying is interrupted by physical constraint or muscular weakness, the risk of crushing will be increased (see Chapter 9).

Sows in crates have been shown to have higher cortisol levels than sows in farrowing pens (Cronin et al, 1991) but only on the day of introduction. Gilts in crates have also been shown to have higher cortisol than gilts in pens, over the immediate pre-farrowing period (Lawrence et al, 1993). Bäckström (1973) has reported a higher incidence of MMA among sows farrowing in crates, which may be due to stress-induced immuno-suppression.

In conclusion, the movement away from confinement towards loose-housing at farrowing would definitely be beneficial to the sow. However, until good litter welfare can be assured, crates should not be phased out. For the sow, freedom would seem to be particularly important just prior to and during farrowing, and to suggest that sows should be confined at this time only, would appear to offer the worst of both options.

10.3.3 The combination of dry sow and farrowing environments

Much research has been done on comparisons of dry sow systems, and much on comparisons of farrowing systems. However, little has been carried out on the effects of the former on the latter. In Chapter 5, it was noted that group-housed sows had higher piglet mortality in pens than in crates, whereas there was no difference between farrowing systems for stall housed sows (which is opposite to results reported by Bäckström [1973] and Hansen & Vestergaard, [1984]). This may indicate that a degree of confinement does help prevent crushing, but only if the sows have good muscular fitness. However, piglet mortality is linked to sow body length in both pens and crates, and therefore, physical confinement can only alleviate rather than eradicate crushing mortality.

With returns to service excluded, group sows farrowing in pens tended to take longer to return to œstrus than sows farrowing in crates. This was especially the case for sows housed in small groups, and may have been as a result of the interruption by weaning, of a stronger mother-offspring bond. The absence of a difference for stall-housed sows may be due to unresponsiveness. Sows from large groups farrowing in crates had more returns to service than sows from large groups farrowing in pens. This may be due to a greater degree of hormonal upset during the weeks following weaning. These sows also tended to lose more body weight during lactation which was opposite to sows from the stalls and small groups.

In terms of pre-parturient behaviour, crated sows which had previously gestated in an open environment changed posture significantly more often than those from any other treatment, indicating the greatest degree of frustration for these sows (see Chapter 6). This result was also reported by Hansen & Vestergaard (1984). Placing group-housed sows into crates altered the amount of time taken to lie down (see Chapter 9), resulting in difficulty of movement, and longer spent pausing during the behaviour.

Group-housed sows in crates had greater peak and average heart rate responses to suckling than stall-housed sows in crates and also a larger change in heart rate from average levels immediately before suckling to peak levels during suckling (see Chapter 7). This may be due to greater frustration caused by the disruption of normal maternal behaviour patterns. Stall-housed sows may not react to the same extent because of an inherent unresponsiveness, or better adaptation to the crates. Confinement also heightened the response of group-housed sows to feeding, again illustrating the discomfort caused by environmental restriction.

In conclusion, for the welfare of the sow, it would appear unreasonable to confine sows during farrowing, if they have previously gestated in an open environment. However, as stated previously, if the welfare of the litter will be worse if the sow farrows in an open system, any decision concerning the continued use of crates at present will have to weigh up the relative merits of sow welfare ***versus*** *piglet welfare. More research needs to be directed at the causes of piglet mortality, so that in future, the decision can be made in favour of sow welfare* ***and*** *piglet welfare.*

10.4 Areas for future research

The studies carried out in this thesis have highlighted a large number of areas which warrant further investigation. For the commercial producer, arguments concerning the banning of certain husbandry systems and the implementation of others, have to be supported by economic feasibility. An interesting question coming out of the production figures (Chapter 5) in this study, is that if the welfare of stall-housed sows is meant to be so poor, why did they produce more piglets than group-housed sows? The fact that they produced significantly larger litters may be explained in terms of higher ovulation rate, a greater efficiency of fertilisation or improved implantation of embryos. There is a need for a thorough investigation to determine what effects the different environmental factors of stall- and group-housing have on the reproductive physiology of the sow.

Other important areas in terms of production are 1) the effects of mixing weaned and served sows back into the herd, 2) factors affecting the length of time taken for the sow to return to œstrus after weaning, and 3) factors affecting piglet mortality. The first area is currently being researched at Cambridge and many other places, and has been identified as a serious problem affecting the efficiency of group-housing systems. Any system that influences the amount of "bullying" of subordinate sows, around the time of mixing, will suffer with an unacceptably high rate of returns to service. The majority of farmers with large group systems, already employ schemes whereby served sows are kept back and reintroduced as a small group into the large group. This will decrease the amount of bullying any single sow receives. However, the figures from Chapter 5 indicate that this is not sufficient to prevent a high number of returns, and thus current experiments are looking at the effects of pre-exposing sows before mixing, and the time of day that mixing occurs.

The results obtained in Chapter 5 would seem to indicate that group-housed sows weaned from pens take longer to return to œstrus than group-housed sows weaned from crates. The hypothesis is that these sows are able to form a greater mother-offspring bond, and are therefore more stressed at weaning. This stress then results in an hormonal imbalance which prolongs the return to œstrus. It would be useful to know whether there is any basis to this hypothesis, and a number of behavioural and physiological measures could be taken around the time of weaning, comparing crated sows with penned sows. The effects of timing, both in terms of time of day (i.e. at feeding time) and age of piglets, could be investigated.

Piglet mortality is a very complex area, but one which is worthy of further investigation. The four week period during which the sow is being suckled, is the biggest single 'loss-point' during the whole rearing process. The current national average piglet mortality rate stands at about 11.7% (MLC figure 1992) with a further 5.4% lost through stillbirths. If these figures could be reduced by even 2-3%, it would have massive implications for the stock in terms of improved welfare and also to the farmer in terms of the economics of production. A great deal of research has focused on the design of farrowing accommodation, but clearly, because piglet mortality has failed to fall further than this 11.7% using a wide variety of farrowing accommodation types, the real answer to a further decrease lies in other directions.

The domestic pig has changed greatly in terms of genetic make-up over the last few decades. Selection has been purely in terms of meat production and has lead to larger, longer-bodied, hybrid sows, giving birth to more, faster-growing piglets. Also, until recently, the majority of sows have been housed in systems that prevent exercise and it is possible that the combination of these factors has altered the sows maternal behavioural repertoire, and her ability to perform them. The results in Chapter 9 indicate that mortality may be part-linked to physical size, and lying behaviour. These links deserve further investigation, especially during the first few days post-partum, both in crates and open farrowing systems. There is also a need for detailed study of lying and standing using kinetic analysis similar to that demonstrated on cattle by Sato & Hasegawa (1993).

To ensure piglet survival, it is essential that there is a rapid onset and sustainment of maternal behaviour. In terms of maternal behaviour, stockmen tend to label their sows either "good" or "bad" mothers, and there needs to be greater emphasis on the selection of breeding stock in terms of maternal behaviour coupled with production, rather than on production alone. Oestradiol was proposed as the primary control of this behaviour (Poindron & Le Neindre, 1980). However, it is clear that there is probably other input from oxytocin, prolactin and various prostaglandins, and that it is the fluctuations in concentration of these hormones at the time of parturition that has overall control of the onset of maternal behaviour patterns. Research in many species has shown very rapid changes in hormone concentrations around this time, including the sow (Robertson et al 1985). Any hormonal dysfunction or suppression towards the tail-end of gestation, is very likely to have serious consequences as regards the survival of the neonates. Relationships between the reproductive hormones and influencing factors, such as chronic or acute stress during gestation and the consequences for survival of the litter, needs investigation.

The apparent increased frustration of group-housed sows farrowing in crates immediately prior to parturition justifies further study, because this combination of dry sow system and farrowing system may shortly become the most common in the UK. There needs to be an emphasis on incidence of nest-building type behaviour coupled with physiological measures such as cortisol concentrations and heart rate. It would also be interesting to compare the responses of gilts with experienced sows in crates for the first time and sows with previous experience of crates.

The ease of use of heart rate monitors in the studies described in Chapter 7, has highlighted a number of areas of applicability. The studies on feeding and agonistic encounters could be developed to assess the responses of dominant and subordinate sows housed in systems employing group-feeding systems such as individual feeding stalls, dump-feeding and trickle-feeding. The study carried out on feeding did appear to indicate a heightened response when feeding occurred in close proximity to other sows. As mentioned above, heart rate monitoring could also be used as an aid to study pre- and post-farrowing behaviour.

The difference in bone strength between systems is an important result, and would benefit from further investigation of the factors contributing to the difference, and also from investigation of the possible consequences for the welfare of the sow. It would also be appropriate, as the UK industry shifts to extensive systems, to compare bone strength and muscle conformation between sows housed outdoors and sows housed indoors in groups and stalls. Further study of the relationship between housing system and lameness incidence is also justified, given the high welfare and economic costs involved.

References

Aherne, F.X. (1982) Some management practices affecting the survival and growth rate of suckling pigs. *Ann. Feeder's Day Rpt.*, Dept. of Animal Science, University of Alberta. **61**: 78-79.

Akil, H., Watson, S., Young, E., Lewis, M., Khachaturian, H. & Walker, J.M. (1984) Endogenous opiods: biology and function. *Ann.Rev.Neurosci.* **7**: 223-225.

Algers, B. (1990) Hormonal release during suckling in the pig in relation to sow and piglet behaviour.In *Proceedings of SVE Congress*, p44-45.

Amit, A. & Galina, Z.H. (1986) Stress induced analgesia: adaptive pain suppression. *Physiol.Rev.* **66**: 1091-1120.

Anderson, J.J.B., Millin, L. & Crackel, W.C. (1971) Effect of exercise on mineral and organic bone turnover in swine. *J.Appl.Physiol.* **30**: 810-813.

Appleby, M.C. & Lawrence, A.B. (1987) Food restriction as a cause of stereotypic behaviour in tethered gilts. *Anim.Prodn.* **45**: 103-110

Appleby, M.C., Lawrence, A.B. & Ilius, A.W. (1989) Influence of neighbours on stereotypic behaviour of tethered sows. *Appl.Anim.Behav.Sci.* **24**: 137-146.

Arey, D.S., Petchey, A.M. & Fowler, V.R. (1991) The preparturient behaviour of sows in enriched pens and the effect of pre-formed nests. *Appl. Anim. Behav. Sci.* **31**: 61-68.

Arey, D.S., Petchey, A.M. & Fowler, V.R. (1992) Farrowing accommodation and piglet mortality. *Farm Building Prog.* **107**: 5-7.

Arnold, G.W. & Morgan, P.D. (1975) Behaviour of the ewe and lamb at lambing and its relationship to lamb mortality. *Appl.Anim.Ethol.* **2**: 25-46.

Arthur, S.R., Kornegay, E.T., Thomas, H.R., Veit, H.P., Notter, D.R., Webb, K.E. & Baker, J.L. (1983) Restricted energy intake and elevated calcium and phosphorus intake for gilts during growth.IV. Characterization of metacarpal, metatarsal, femur, humerus and turbinate bones of sows during three parities.*J.Anim.Sci.* **57**:1200-1214.

Aumaitre, A. & Le Dividich, J.(1984) Improvement of piglet survival rate in relation to farrowing systems and conditions. *Ann.Rech.Vet.* **15**: 173-179.

Bäckström, L. (1973) Environment and animal health in piglet production. *Acta. vet. Scand.* suppl **41**: 1-240.

Baldock, N.M. (1985) Heart-rate and behaviour recorded in sheep during undisturbed conditions and various husbandry practices. *Ph.D. thesis* Univ. of Reading.

Baldock, N.M. Sibley, R.M. & Penning, P.D. (1988) Behaviour and seasonal variation in heart rate in domestic sheep (Ovis aries). *Anim.Behav.* **36**, 35-43.

Barnes, M.A., Carter, R.E., Longnecker, J.V., Riesen, J.W. & Woody, C.O. (1975) Age at transport and calf survival. *J.Dairy Sci.* **58**: 1247.

Barnett, J.L, Cronin, G.M. ,Winfield, C.G. & Dewar, A.M. (1984) The welfare of adult pigs, the effects of 5 housing treatments on behaviour, plasma corticosteroids and injuries. *Appl.Anim.Behav.Sci.* **12**: 209-232.

Barnett, J.L., Hemsworth, P.H. & Winfield, C.G.(1987) The effects of design of individual stalls on the social behaviour and physiological responses related to the welfare of pregnant pigs. *Appl.Anim.Behav.Sci.* **18**: 133-142.

Barnett, J.L., Hemsworth, P.H.,Winfield, C.G. & Hansen, C. (1986) Effects of social environment on welfare status and sexual behaviour of female pigs.I.Effect of group size. *Appl.Anim.Behav.Sci.* **16**: 249-257.

Barnett, J.L., Winfield, C.G., Cronin, G.M., Hemsworth, P.H. & Dewar, A.M. (1985) The effect of individual and group housing on behavioural and physiological responses related to the welfare of pregnant pigs. *Appl. Anim. Behav. Sci.* **14**: 149-161.

Baxter, M.R. (1991) The "freedom" farrowing system. *Farm Building Progress* **104**: 9-15.

Baxter, M.R. & Schwaller, C. (1983) Space requirements for sows in confinement , in "Farm Animal Housing and Welfare" *Curr.Topics Vet.Med.Anim.Sci.* Martinus Nijhoff.

Baxter, S.H. (1984) *Intensive Pig Production: Environmental Management and Design.* Granada, London.

Bayley, H.S., Arthur, D., Bowman, G.H., Pos, J. & Thompson, R.G. (1975) Influence of dietary phosphorus level on growth and bone development in boars and gilts.*J. Anim.Sci.* **40**: 864-870.

Bengtsson, A.C., Svendsen, J. & Persson, G. (1983) Comparison of four types of housing for sows in gestation: behaviour studies and hygiene studies. *Sveriges Lantbruksuniversitet, Institutionen for Lantbrukets Byggnadsteknik, Rapport*, **36**, 76pp Lund.

Bergeron, R., Gonyou, H.W. & Eurell, T.E. (1993) Behavioural and physiological responses of Meishan, Yorkshire and crossbred gilts to conventional and turn-around gestation stalls. *J.Anim.Sci.* **71**(suppl 1): 112 (Abstr.).

Blackshaw, J.K. & Hagelsø, A.M. (1990) Getting-up and lying-down behaviours of loose-housed sows and social contacts between sows and piglets during day 1 and day 8 after parturition. *Appl. Anim. Behav. Sci.* **25**: 61-70.

Blackshaw, J.K. & McVeigh, J.F. (1984) Stereotype behaviour in sows and gilts housed in stall , tethers and groups. In *Advances in animal welfare science* 163-174. *Curr. Topics Vet.Med.Anim.Sci.* Martinus Nijhoff.

Blecha, F., Pollmann, D.S. & Nichols, D.A. (1983) Weaning pigs at an early age decreases cellular immunity. *J.Anim.Sci.* **56**: 396-400.

Block, W. (1985) Survival on land. *Biologist.* **32**: 132-138.

Bloom, S.R, Edwards, A.V, Hardy, R.M., Malinowska, K. & Silver, M. (1975) Cardiovascular and endocrine responses to feeding in young calves. *J.Physiol.* **253**, 135-155.

Bokma, S (1990) Housing and management of dry sows in groups in practice: partly slatted systems. *Proc. Int. Symp. Elec. Id. in Pig Prod.* RASE Stonleigh. 37-45.

Brantas, G.C. (1980) The pre-laying behaviour of laying hens in cages, with and without laying nests. In *The Laying Hen and its Environment*, ed. R.Moss, *Curr. Top. vet. Med. Anim. Sci.* **8**: 227-234. The Hague, Martinus Nijhoff.

Breazile, J.E. (1988) The physiology of stress and its relationship to mechanisms of disease and therapeutics.*Vet.Clinics N.Amer.Food Anim.Prod* . **4.3**: 441-480.

Bridges, R.S.(1984) A quantitative analysis of the roles of dosage, sequence and duration of œstradiol and progesterone exposure in the regulation of maternal behaviour in the rat.*Endocr.* **114:** 930-940.

Brion, A. (1964) Les tics chez les animaux. In *Psychiatrie Animale*, ed A.Brion & H.Ey, 299-306. Paris: Desclée de Brouwer.

Broom, D.M.(1982) Husbandry methods leading to inadequate social and maternal behaviour in cattle. In: Disturbed Behaviour in Farm Animals. Bessei,W.(Ed.) *Hohenheimer Arbeiten*, **121**: 42-50.

Broom, D.M. (1986a) Indicators of poor welfare. *Br.Vet.J.* **142**: 524-526

Broom, D.M. (1986b) Stereotypies and responsiveness as welfare indicators in stall-housed sows. *Anim. Prod* .. **42**: 438-439.

Broom, D.M.(1986c) Responsiveness of stall-housed sows. *Appl. Anim. Behav.Sci.* **15**, 186.

Broom, D.M.(1987) Applications of neurobiological studies to farm animal welfare. In *Biology of stress in farm animals: an integrated approach*, ed. P.R.Wiepkema and P.W.M.van Adrichem. *Curr.Top.vet.Med.Anim.Sci.* **42**, 101-110. Martinus Nijhoff, Dordrecht.

Broom, D.M. (1988) The scientific assessment of animal welfare. *Appl.Anim.Behav.Sci.* **20**: 5-19.

Broom, D.M. & Johnson, K.(1993) *Stress and Animal Welfare.* Chapman & Hall. London.

Broom, D.M. & Kennedy, M.J. (1993) Stereotypies in horses: their relevance to welfare and causation. *Equine vet. Educ.* **5**: 151-154.

Broom, D.M. & Leaver, J.D.(1978) The effects of group-housing or partial isoloation on later social behaviour of calves. *Anim.Behav.* **26**: 1255-1263.

Broom, D.M. & Potter, M.J. (1984) Factors affecting the occurrence of stereotypies in stall-housed dry sows. *Proc. Int. Cong. Appl. Ethol. Farm Animals.* 229-231.

Buckland, R.B., Goldrosen, A. & Bernon, D.E.(1974) Effect of blood sampling by cardiac puncture on subsequent body weight of broilers and S.C. White Leghorn replacement pullets. *Poultry Sci.* **53**: 1256-1258.

Cariolet, R. & Dantzer, R. (1985) Activité motrice des truises attachées durant la gestation: mise en evidence de quelques facteurs de variations. *Journées Rech. Porcine en France.* **17**, 237-248.

Carpenter, E. (1980) in *"Animals and ethics"*. Watkins London.

Carter, A & English, P.R.(1983) A comparison of the activity and behaviour of dry sows in different housing and penning systems. *Anim.Prod.* **36**, 531.

Coe, C.L, Lubach, G.R, Ershler, W.B. & Klopp, R.G. (1989) Influence of early rearing on lymphocyte proliferation responses in juvenile rhesus monkeys. *Brain Behav. Immun.* **3**: 47-60.

Collins, E.R., Kornegay, E.T. & Bonnette, E.D.(1987) The effects of two confinement systems on the performance of nursing sows and their litters. *Appl.Anim.Behav. Sci.* **17**: 51-59.

Combs, N.R., Kornegay, E.T., Lindemann, M.D., Notter, D.R., Wilson, J.H. & Mason, J.P. (1991) Calcium and phosphorus requirement of swine from weaning to market weight: II development of response curves for bone criteria and comparison of bending and shear bone testing. *J.Anim.Sci.* **69**: 682-693.

Cooper, T., Trunkfield, H., Zanella, A. & Booth, W. (1989) An enzyme-linked immunoabsorbent assay for cortisol in the saliva of man and domestic farm animals. *J.Endocr.* **123**: R13-16.

Crenshaw, T.D., Peo, Jr., E.R., Lewis, A.J. & Moser, B.D. (1981) Bone strength as a trait for assessing mineralization in swine: a critical review of techniques involved.*J.Anim.Sci.* **53**: 827-835.

Cronin, G.M., Barnett, J.L., Hodge, F.M., Smith, J.A. & McCallum, T.H. (1991) The welfare of pigs in two farrowing/lactation environments: cortisol responses of sows. *Appl. Anim. Behav. Sci.* **32**: 117-127.

Cronin, G.M., Hemsworth, P.H., Winfield, C.G., Muller, B. & Chamley, W.A. (1983) The incidence of and factors associated with failure to mate by 245 days of age in the gilt. *Anim.Reprod.Sci.* **5**: 199-205.

Cronin, G.M., Schirmer, B.N., McCallum, T.H., Smith, J.A. & Butler, K.L. (1993) The effects of providing sawdust to pre-parturient sows in farrowing crates on sow behaviour, the duration of parturition and the occurrence of intra-partum stillborn piglets. *Appl.Anim.Behav.Sci.* **36**: 301-315.

Cronin, G.M. & Simpson, G.J. (in press) Piglet survival in a conventional crate versus an "alternative" farrowing system. *Manipulating Pig Production IV.*

Cronin, G.M. & Smith, J.A.(1992a) The effects of accommodation type and straw bedding around parturition and during lactation on the behaviour of primiparous sows and survival and growth of piglets to weaning. *Appl.Anim.Behav.Sci.* **33**: 191-208.

Cronin, G.M. & Smith, J.A.(1992b) Suckling behaviour of sows in farrowing crates and straw-bedded pens. *Appl. Anim. Behav. Sci.* **33**: 175-189.

Cronin, G.M. & van Amerongen, G.(1991) The effects of modifying the farrowing environment on sow behaviour and survival and growth of piglets. *Appl.Anim. Behav.Sci.* **30**: 287-298.

Cronin, G.M.&Wiepkema, P.R.(1984) An analysis of stereotyped behaviour in tethered sows. Ann.Rech.Vet. **15** : 263-270.

Cronin, G.M., Wiepkema, P.R. & Hofstede, G.J.(1984) The development of stereotypies in tethered sows. In: *Proc.Int.Cong.Appl.Ethol.Farm Animals.* Dalmstadt, KTBL. 97-100.

Cronin, G.M, Wiepkema, P.R. & van Ree, J.M. (1985) Endogenous opioids are involved in abnormal stereotyped behaviours in tethered sows *Neuropeptides* **6**: 527-530.

Cronin, G.M, Wiepkema, P.R. & van Ree, J.M.(1986) Endorphins implicated in stereotypies of tethered sows. *Experientia* **42**: 198-199.

Csermely, D. & Wood-Gush, D.G.M. (1986) Agonistic behaviour in grouped sows. *Biol.Behav.* **11**: 244-252.

Currey, J.D. (1968) The effect of protection on the impact strength of rabbits' bones. *Acta Anatomica.* **71**: 87-93.

Curtis, S.E., Hurst, R.J., Widowski, T., Shanks, R.,Jensen, A., Gonyou, D., Bane, A., Muehling, A. & Kesler, R. (1989) Effects of sow-crate design on health and performance of sows and piglets. *J.Anim.Sci.* **67**: 80-93.

Dantzer, R.(1986) Behavioral, physiological, and functional aspects of stereotyped behaviour: a review and a re-interpretation. *J.Anim.Sci.* **62**: 1776-1786.

Dantzer, R.,Bluthé, R. & Tazi, A. (1986) Stress-induced analgesia in pigs. *Ann.Rech.Vet.* **17**: 147-151.

Dantzer, R. & Mormède, P. (1981) Pituitary-adrenal consequences of adjunctive behaviours in pigs. *Horm.Behav.* **15**: 386-395.

Dantzer, R. & Mormède, P. (1983) De-arousal properties of stereotyped behaviour: evidence from pituitary-adrenal correlates in pigs. *Appl.Anim.Ethol.* **10**: 233-244.

Dantzer, R., Mormède, P. & Henry, J.P.(1983) Physiological assessment of adaptation in farm animals. In: Farm animal housing and welfare. Baxter,S.H.,Baxter,M.R.& MacCormack,J.A.C. (Eds) *Curr.Top.Vet.Med.Anim.Sci.,* Martinus Nijhoff: 8-19

Dauncey, M.J.& James, W.P.T.(1979) Assessment of heart-rate method for determining energy expenditure in man using a whole body calorimeter.*Br.J.Nutr.* **42:** 1-13.

De Passillé, A.M.B. & Roberts, S. (1989) Behaviour of lactating sows; influence of stage of lactation and husbandry practices at weaning. *Appl. Anim. Behav. Sci.* **23**: 315-329.

Devilat, J., Camps, J. & Skoknic, A. (1971) Farrowing crate and conventional pen for sows. *J.Anim.Sci.* **33**: 208 (Abstr.)

Dittrich, L.(1984) On the necessity to promote the activity of zoo-kept wild animals by artificial stimuli . In "*Proc.Int.Cong.Appl.Eth.Farm Anim.* 283-287.

Donaldson, S.L.(1970) The effects of early feeding and rearing experience on social maternal and milking parlour behaviour in dairy cattle. Ph.D. thesis, Purdue University.

Dougherty, R.W. (1976) Problems associated with feeding farm livestock under intensive systems. *World Rev.Nutr.Diet.* **25**: 249-275.

Duncan, I.J.H. & Dawkins, M.S. (1983) The problems of assessing " well-being" and "suffering" in farm animals. In 'Indicators relevant to farm animal welfare'.*Curr. Topics Vet. Med. Anim. Sci.* Martinus Nijhoff.

Dyck, G.W. & Swierstra, E.E. (1987) Causes of piglet death from birth to weaning.*Can.J. Anim.Sci.* **67**: 543-547.

Edwards, S.A. (1985) Group housing systems for dry sows. *Farm Building Progress* **80**: 19-22.

Edwards, S.A., Brouns, F. & Stewart, A.H. (1993) Influence of feeding system on the welfare and production of group-housed sows. In *Livestock Environment IV.* 166-172. Proc. Am. Soc. Agric. Eng. St Joseph, Michigan.

Ekesbo, I., Jensen, P. & Hogsved, O. (1978) Nygammal typ ab Sinsuggehallning nagra etologiska data. *Startryck ur Svensk Veterinartidning.* **30(23)**: 845-848.

English, P.R. & Morrison, V.(1984) Causes and prevention of piglet mortality. *Pig News & info.* **5**: 369-376.

English, P.R. & Smith, W.J.(1975) Some causes of death in neonatal piglets.*Vet.Ann.* **15**: 95-104.

English, P.R., Smith, W.J. & MacLean, A. (1977) The Sow - improving her efficiency. Farming Press Ltd, Ipswich,UK.

English, P.R. & Wilkinson, V.(1982) Management of the sow and litter in late pregnancy and lactation in relation to piglet survival and growth. In: *Control of Pig Production* (Eds, D.J.A.Cole & G.R.Foxcroft) London, Butterworth's, 479-506.

Esterling, B. & Rabin, B.S. (1987) Stress-induced alteration of T-lymphocyte subsets and humoral immunity in mice. *Behav. Neurosci.* **101**: 115-119.

Ewbank, R.(1985) Behavioural responses to stress in farm animals. In: Moberg,G.P.(Ed.), *Animal Stress.* Am.Physiol.Soc., Bethesda,Maryland. 71-79.

Ewbank, R.(1988) Animal Welfare. From: *Management and Welfare of Farm Animals.* Bailliere Tindall, London. 1-12.

Fahmy, M.H. & Dufour, J.J.(1976) Effects of post-weaning stress and feeding management on return to œstrus and reproductive traits during early pregnancy in swine. *Anim.Prod.* **23**: 103-110.

Fokkema, D.S.(1985) Social behaviour and blood pressure: a study of rats. Ph.D.Thesis. University of Groningen.

Fraser, A.F. (1960) Spontaneously occurring forms of "tonic immobility" in farm animals. *Canad.J.comp.Med.* **24**: 330-332.

Fraser, A.F. & Broom, D.M. (1990) *Farm Animal Behaviour and Welfare.* 3rd Ed. Bailiére Tindall: London.

Fraser, D. (1975) The effects of straw on the behaviour of sows in tether stalls. *Anim. Prod* . **21**: 59-68.

Fraser, D. (1990) Behavioural perspectives on piglet survival. *J.Reprod.Fert. suppl.***40**: 355-370.

Fraser, D., Thompson, B.K., Ferguson, D.K. & Darroch, R.L. (1979) The 'teat order' of suckling pigs. 3. Relation to competition within litters. J. agric. Sci. Camb. **92**: 257-261.

Freeman, B.M., Kettlewell, P.J., Manning, A.G.C. & Berry, P.S. (1984) Stress of transportation for broilers. *Vet. Rec.* **114**: 286-287.

Giraldi, T., Perissin, S.,Zorzet, S., Piccini, P. & Rapozzi, V. (1989) Effects of stress on tumor growth and metastsis in mice bearing Lewis lung carcinoma. *Eur.J.Cancer Clin.Oncol.* **25**: 1583-1588.

Glastonbury, J.R.W. (1976) A survey of preweaning mortality in the pig. *Austr. vet. J.* **52**: 272-276.

Goedegebuure, S.A., Häni, H.J., van der Valk, P.C. & van der Wal, P.G. (1980) Osteochondrosis in six breeds of slaughter pigs. *Vet.Q.* **2**: 28-41.

Gonyou, H.W., Hemsworth, P.H. & Barnett, J.L.(1986) Effects of frequent interactions with humans on growing pigs. *Appl.Anim.Behav.Sci.* **16**: 269-278.

Götz, M. (1991) Changes in nursing and suckling behaviour of sows and their piglets in farrowing crates. *Appl. Anim. Behav. Sci.* **31**: 271-275.

Gravås, L. (1982) Production and behaviour of free moving and locked sows. Proc.Second int. Livestock Eur.Symp., 411-419. St.Joseph, Mich., Am. Soc. Agric. Eng.

Grandhi, R.R., Thornton-Trump, A.B. & Doige, C.E. (1986) Influence of dietary calcium-phosphorus levels on certain mechanical, physical and histological properties and chemical composition of bones in gilts and second litter sows.*Can.J.Anim.Sci.* **66**: 495-503.

Gregory, N.J. & Wilkins, L.J. (1989) Broken bones in domestic fowl: handling and processing damage in end-of-lay battery hens. *British Poultry Sci.* **30**: 555-562.

Gregory, N.J. & Wotton, S.B.(1981) Autonomic and non-autonomic control of cardiovascular function in stress-sensitive pigs. *J.Vet.Pharmacol.Therap.* **4**, 183-191

Grøndalen, T. (1974) Osteochondrosis and Arthrosis in pigs II. Incidence in breeding animals. *Acta Vet.Scand.* **15**: 26-42.

Gross, W.B. & Siegel, P.B. (1981) Long-term exposure of chickens to three levels of social stress. *Avian Dis.* **25**: 312-325.

Gustafsson, B. (1982) Effects of sow housing systems in practical pig production. *Livestock Environment II*, ASAE Proc. 2nd Int.Livestock Env.Symp. 380-391.

Hall, D.D., Cromwell, G.L. & Stahly, T.S. (1991) Effects of dietary calcium, phosphorus, calcium:phosphorus ratio and vitamin K on performance, bone strength and blood clotting status of pigs. *J.Anim.Sci.* **69**: 646-655.

Hansen, L.L. & Vestergaard, K. (1984) Tethered v. loose sows. Ethological observations and measures of productivity. II production results *Ann.Rech.Vet.* **15**: 185-191.

Hansen, K.E. & Curtis, S.E. (1981) Prepartal activity of sows in stall or pen *J.Anim.Sci.* **51:** 456-460.

den Hartog, L.A., Backus, G.B.C. & Vermeer, H.M.(1993) Evaluation of housing systems for sows. *J.Anim.Sci.* **71**: 1339-1344.

Heckt, W.L., Widowski, T.M., Curtis, S.E. & Gonyou, H.W. (1988) Prepartum behaviour of gilts in three farrowing environments. *J.Anim.Sci.* **66**: 1378-

Hemsworth, P.H., Winfield, C.G. & Mullaney, P.G. (1976) A study of the development of the teat-order in piglets. *Appl. Anim. Ethol.* **2**: 225-233.

Hemsworth, P.H. & Barnett, J.L. (1991) The effects of aversively handling pigs, either individually or in groups, on their behaviour, growth and corticosteroids. *Appl.Anim. Behav. Sci.* **30**: 61-72.

Hemsworth, P.H., Barnett, J.L. & Hansen, C. (1981) The influence of handling by humans on the behaviour, growth and corticosteroids in the juvenile female pig. *Hormones & Behav.* **15**: 396-403.

Hemsworth, P.H., Barnett, J.L. & Hansen, C. (1986b) The influence of handling by humans on the behaviour, reproduction and corticosteroids of young pigs. *Appl.Anim. Behav. Sci.* **15**: 303-314.

Hemsworth, P.H., Barnett, J.L. & Hansen, C. (1987) The influence of inconsistent handling on the behaviour, growth and corticosteroids of young pigs. *Appl. Anim. Behav. Sci.* **17**: 245-252.

Hemsworth, P.H., Barnett, J .L., Hansen, C. & Winfield, C.G. (1986a) Effects of social environment on welfare status and sexual behaviour of female pigs.II Effects of space allowance. *Appl.Anim.Behav.Sci.* **16**: 259-267.

Hemsworth, P.H., Salden, N.T.C.J. & Hoogerbrugge, A. (1982) The influence of the post-weaning social environment on the weaning to mating interval of the sow. *Anim.Prod.*35: 41-48.

Hennessy, D.P. & Williamson, P.(1983) The effects of stress and of ACTH administration on hormone profiles, œstrus and ovulation in pigs. *Theriogenology.* **20**: 13-27.

Herlin, A.H. (1990) Lying-down behaviour of loose-housed and tied-up dairy cows. (Abstract) *SVE 3rd Nordic Meeting*, November 1990.

Hessing, M.J.C., Hagelso, A.M., van Beek, J.A.M., Wiepkema, P.R., Schouten, W.G.P. & Krukow, R.(1993) Individual behavioural characteristics in pigs. *Appl.Anim.Behav. Sci.* **37**: 285-295.

Higginson, S. (1989) Farrowing nests: alternative to the crate? *Pig Farming.* **37**: 10-12.

Holmes, C.W., Stephens, D.B. & Toner, J.N.(1976) Heart-rate as a possible indicator of the energy metabolism of calves kept out-of-doors. *Livestock Prod.Sci.* **3**: 333-343

Honkvaara, M. (1988) Influence of porcine stress on blood composition and early post-mortem meat quality in pigs of different halothane genotypes. *Meat Sci.* **24**: 21-29.

Horrell, R.I. (1982) Immediate behavioural consequences of fostering 1-week-old piglets. *J. agric. Sci., Camb.* **99**: 329-336.

Horrell, R.I. & Bennett, J. (1981) Disruption of teat preferences and retardation of growth following cross-fostering of 1-week-old pigs. *Anim. Prod.* **33**: 99-106.

Horrell, R.I. & Eaton, M. (1984) Recognition of maternal environment in piglets: effects of age and some discrete complex stimuli. *Quart. J. Exp. Psych.* **36B**: 119-130.

Horrell, R.I. & Hodgson, J. (1992a) The bases of sow-piglet identification. 1.The identification by sows of their own piglets and the presence of intruders. *Appl. Anim. Behav. Sci.* **33**: 319-327.

Horrell, R.I. & Hodgson, J. (1992b) The bases of sow-piglet identification. 2. Cues used by piglets to identify their dam and home pen. *Appl. Anim. Behav. Sci.* **33**: 329-343.

Houpt, K.A. & Olm, D. (1984) Foal rejection: A review of 23 cases. *Equine Pract.* **6(7)**: 38-40.

Houwers, H.W.J., Buré, R.G. & Koomans, P.(1992) Behaviour of sows in a free-access farrowing house. *Farm Build.Prog.* **109**: 9-11.

Hughes, B.O. (1976) Behaviour as an indicator of welfare. *Proc.V.Europ.Poult.Conf.* Malta. 1005-1018.

Hunt, K.A. & Petchey, A.M. (1989) Degree of enclosure preferred by sows around farrowing. Anim. Prod. **48**: 643. (Abstr.)

Hunter, E.J, Broom, D.M, Edwards, S.A. & Sibly, R.M.(1988) Social hierarchy and feeder access in a group of 20 sows using a computer-controlled feeder. *Anim. Prod* . **47:** 139-148.

Hunter, M.G. & Wiesak, T. (1990) Evidence for and implications of follicular heterogeneity in pigs. *J.Reprod.Fert.* (suppl) **40**: 323-341.

Hutson, G.D. & Haskell, M.I. (1990) The behaviour of farrowing sows with free and operant access to an earth floor. *Appl. Anim. Behav. Sci.* **26**: 363-372.

Jacobsen, N.K.(1979) Changes in heart-rate with growth and activity of white-tailed deer fawns.*Comp.Biochem.Physiol.* **62A** : 885-888

Jensen, A.H., Yen, J.T., Gehring, M.M., Baker, D.H., Becker, D.E. & Harmon, B.G. (1970) Effects of space restriction and management on pre- and post-pubertal response of female swine. *J.Anim.Sci.* **31**: 745-750.

Jensen, P.(1979) Sinsuggors beteendemonster under tre olika upstallnings forhallanden-en pilot studie. *Institutionen for husdjurshygien med horslarskalan. Rapport.* **1**: 1-40. Uppsala, Sveriges Lantbruksuniversitet.

Jensen, P. (1980) Fixeringens effect pa sinsuggors beteende - en etologisk studie. *Institutionen for husdjurshygien med horslarskalan. Rapport.* **2**: 1-66. Uppsala, Sveriges Lantbruksuniversitet.

Jensen, P. (1981) Fixeringens effect pa sinsuggors beteende. *Svensk veterinartidning.* **33**: 73-78.

Jensen, P. (1986) Observations on the maternal behaviour of free-ranging domestic pigs. *Appl.Anim.Behav.Sci.* **16**: 131-142.

Jensen, P. (1988a) Maternal behaviour and mother-young interactions during lactation in free-ranging domestic pigs. *Appl.Anim.Behav.Sci.* **20**: 297-308.

Jensen, P. (1988b) Maternal behaviour of free-ranging pigs. I: Results of a three-year study. Dept. of Animal Hygiene, Skara, Report 22.

Jensen, P. (1989) Nest site choice and nest building of free-ranging domestic pigs due to farrow. *Appl. Anim. Behav. Sci.* **22**: 13-21.

Jensen, P. (1990) Who needs behavioural needs?-Nest-building in sows as an example. (Abstract) *S.V.E.3rd Nordic Meeting.*

Jensen, P., Floren, K. & Hobroh, I.(1987) Peri-parturient changes in behaviour in free-ranging domestic pigs. *Appl.Anim.Behav.Sci.* **17**: 69-76.

Jensen, P. & Recén, B. (1989) When to wean - observations from free ranging domestic pigs. *Appl. Anim. Behav. Sci.* **23**: 49-60.

Jensen, P. & Redbø, I.(1987) Behaviour during nest-leaving in free-ranging domestic pigs. *Appl.Anim.Behav.Sci.* **18**: 355-362.

Jensen, P., Stangel, G. & Algers, B. (1991) Nursing and suckling behaviour of semi-naturally kept pigs during the first 10 days post-partum. *Appl. Anim. Behav. Sci.* **31**: 195-209.

Jeppesen, L.E. (1982a) Teat-order in groups of piglets reared on an artificial sow. I. Formation of teat-order and influence of milk yield on teat preference. *Appl. Anim. Ethol.* **8**: 335-345.

Jeppesen, L.E. (1982b) Teat-order in groups of piglets reared on an artificial sow. II. Maintenance of teat-order with some evidence for the use of odour cues. *Appl. Anim. Ethol.* **8**: 347-355.

Johansson, G. & Jönsson, G. (1977) Myocardial cell damage in the porcine stress syndrome. *J.Comp.Pathol.* **87**: 67-74.

Johansson, G., Olsson, K., Haggendal, J., Jonsson, L. & Thoren-Tolling, K. (1982) Effects of stress on myocardial cells and blood levels of catecholamines in normal and amygdalectomised pigs. *Can.J.Comp.Med.* **46**: 176-182.

Kelley, K.W. (1980) Stress and immune function: a bibliographic review. *Ann.Rech.Vet.* **11**: 445-478.

Kelley, K.W. (1985) Immunological consequences of changing environmental stimuli. In *Animal Stress.* 193-223. American Physiological Association.

Kennedy, M.J., Schwabe, A.E. & Broom, D.M. (1993) Crib-biting and wind-sucking stereotypies in the horse. *Equine vet. Educ.* **5**: 142-147.

Kiley-Worthington, M. (1977) *Behavioural Problems of Farm Animals*. Stocksfield: Oriel Press.

Knowles, T.G. (1990) The welfare of hens in transit and related effects of housing system. Ph.D. Thesis, University of Cambridge.

Knowles, T.G. & Broom, D.M. (1990) Limb bone strength and movement in laying hens from different housing systems.*Vet.Rec.* **126**: 354-356.

de Koning, R. (1983) Results of a methodical approach with regard to external lesions of sows as an indicator of animal well being. In *Indicators Relevant to Farm Animal Welfare*, ed. D.Smidt, *Curr.Top.vet.Med.Anim.Sci.* **23**: 155-162. The Hague, Martinus Nijhoff.

Kornegay, E.T., Thomas, H.R. & Meacham, T.N. (1973) Evaluation of dietary calcium and phosphorus for reproducing sows housed in total confinement or in dirt lots. *J.Anim.Sci.* **37**: 493-500.

Krohn, C.C. & Munksgaard, L.(1993)Behaviour of dairy cows kept in extensive (loose housing/pasture) or intensive (tie stall) environments. II Lying and lying-down behaviour. *Appl.Anim.Behav.Sci.* **37**: 1-16

Lambert, R.J., Ellis, M. & Rowlinson, P. (1983) An alternative system of sow housing and feeding based upon a sow-activated feeder. *Anim. Prod.* **36**: 532.

Lambert, R.J., Ellis, M. & Rowlinson, P. (1984) The effect of feeding frequency on the behaviour patterns of group-housed dry sows using an electronic sow-activated feeder. *Anim. Prod.* **38**: 540.

Lambert, R.J., Ellis, M. & Rowlinson, P. (1985) The effect of feeding frequency on levels of aggression and 24 behaviour patterns of large groups of loose-housed dry sows. Anim. Prod. **40**: 546.

Lammers, G.J. & de Lange, A (1986) Pre- and post-farrowing behaviour in primiparous domestic pigs. *Appl. Anim. Behav. Sci.* **15**: 31-43.

Lanyon, L.E. (1984) Functional strain as a determinant for bone remodelling. *Calcified Tissue International* **36:** S56-S61.

Lanyon, L.E. (1987) Functional strain in bone tissue as an objective, and controlling stimulus for adaptive bone remodelling. *J.Biomech.* **20**: 1083-1093.

Lawrence, A.B., Petherick, C.J., McLean, K.A., Deans, L.A., Chirnside, J. & Vaughan, A. (1993) The effect of environment on plasma cortisol in parturient sows. *Anim. Prod.* **56**: 476 (Abstr.).

Lawrence, A.B., Terlouw, E.M.C. & Illius, A.W.(1991) Individual differences in behavioural responses of pigs exposed to non-social and social challenges. *Appl.Anim.Behav.Sci.* **30**: 75-86.

Lewis, N.J. & Hurnik, J.F. (1985) The development of nursing behaviour in Swine. *Appl. Anim. Behav. Sci.* **14**: 225-232.

Lorz, A. (1973) Tierschutzgesetz. Kommentar, Munchen. Verlag. C.H.Beck.

Lou, Z. & Hurnik, F.J. (1993) The development of alternative farrowing crate for sows. In *Proc. of the Int.Cong. on Appl. Ethol.* p417-420, ed. M.Nichelmann, H.K.Wierenga & S.Braun. Humboldt University, Berlin.

MacArthur, R.A, Johnston, R.H. & Geist, V.(1979) Factors influencing heart-rate in free-ranging bighorn sheep: a physiological approach to the study of wildlife harassment. *Can.J.Zool.* **52**: 2010-2021.

Maclean, C.W.(1969) Observations on non-infectious infertility in sows. *Vet.Rec.* **85**: 675-682

Madec, F. (1984) Urinary disorders in intensive pig herds. *Pig News & Info.* **5**: 89-93.

Madec, F. (1985) La consommation d'eau chez la truie gestante en élevage intensif. *Journées Rech. Porcine en France.* **17**: 223-236.

Manser, C.E. (1992) *The Assessment of Stress in Laboratory Animals.* RSPCA. Horsham, Sussex.

Marchant, J.N. & Broom, D.M.(1993) The effects of dry-sow housing conditions on lying behaviour. In *Proc.of the Int.Cong.on Appl.Ethol.* 455-458, ed. M.Nichelmann, H.K.Wierenga & S.Braun. Humboldt University, Berlin.

Marrable, A.W. (1971) In *The embryonic pig: a chronological account.* Pitman Medical, London.

Mason, G.J.(1991) Stereotypies: a critical review. *Anim.Behav.* **41**: 1015-1038.

Matsukawa, K. & Ninomija, I.(1987) Changes in renal sympathetic nerve activity, heart rate and arterial blood pressure associated with eating in cats. *J.Physiol.* **390**, 229-242

Mavrogenis, A.P. & Robinson, O.W. (1976) Factors affecting puberty in swine. *J.Anim. Sci.* **42**: 1251-1255.

McBride, G. (1963) The "teat-order" and communication in young pigs. *Anim. Behav.* **11**: 53-56.

McGlone, J.J. & Blecha, F.(1987) An examination of behavioural, immunological and productive traits in four management systems for sows and piglets. *Appl.Anim. Behav.Sci.* **18**: 269-286.

McGlone, J.J., Hicks, T.A., Salak, J.L., Nicholson, R.I. & Norman, R.L. (1993) Crates and girth tethers for gestating and lactating sows: reproductive performance, behavior, immune function and ergonomics. *J.Anim.Sci.* **71**(suppl 1): 112 (Abstr.)

McLean, K.A., Baxter, M.R. & Michie, W. (1986) A comparison of the welfare of laying hens in battery cages and a perchery. *Res.Devel.Agric.* **3**: 93-98.

Mendl, M.T., Broom, D.M. & Zanella, A.J. (1991) Adrenal cortex activity, reproduction and welfare of pregnant sows in a group housing system. *Anim. Prod.* **52**: 578 (Abstr.).

Mendl, M.T., Broom, D.M. & Zanella, A.J. (1993) The effects of three types of dry sow housing on sow welfare. In: *Livestock Environment IV*, ed. Collins, E. & Boon, C. 461-467. St.Joseph, Michigan : American Society of Agricultural Engineers, 1993

Mendl, M., Zanella, A.J. & Broom, D.M.(1992) Physiological and reproductive correlates of behavioural strategies in female domestic pigs. *Anim.Behav.* **44**: 1107-1121.

Meredith, M.J. (1982) Anœstrus in the pig: diagnosis and aetiology.*Irish Vet.J.* **36**: 17-24.

Merkley, J.W. & Wabeck, C.J. (1975) Cage density and frozen storage effect on bone strength of broilers. *Poultry Sci.* **54**: 1624-1627.

Mertshing, H.J. & Kelley, K.W. (1983) Restraint reduces size of thymus gland and PHA skin swelling in pigs. *J.Anim.Sci.* **57**: 175 (Abstr.).

Meunier-Saläun, M.C., Gort, F., Prunier, A. & Schouten, W.P.G. (1991) Behavioural patterns and progesterone, cortisol and prolactin levels around parturition in European (Large White) and Chinese (Meishan) sows. *Appl.Anim.Behav.Sci.* **31**: 43-59.

Meyer, W.A. & Sunde, M.L. (1974) Bone breakage as affected by type of housing or an exercise machine for layers. *Poult.Sci.* **53**: 878-885.

Michie, E.A.(1967) Urinary estriol excretion in pregnancies complicated by suspected retarded intrauterine growth , toxemia or essentialhypertension. *J.Obstet. Gynaecol. Br. Commonw.* **74 :** 896-901

von Mickwitz, G. (1982) Various transport conditions and their influence on physiological reaction. In *Transport of Animals Intended for Breeding, Production and Slaughter.* ed. R.Moss. 45-53. Martinus Nijhoff.

M.L.C. (1991) Pig Yearbook, Meat & Livestock Commission, Milton Keynes.

M.L.C. (1993) Pig Yearbook, Meat & Livestock Commission, Milton Keynes.

Monjon, A.A. & Collecter, M.I. (1977) Stress-induced modulation of the immune response. *Science* **196**: 307-308.

Morishima, H.O, Yeh, M.N. & James, L.S. (1979) Reduced uterine blood flow and fetal hypoxemia with acute maternal stress . Experimental observation in the pregnant baboon. *Am. J. Obstet. Gynaecol.* **134**: ` 270-275.

Mormède, P., Soissons, J., Bluthé, R., Raoult, J., Legarff, G., Levierax, D. & Dantzer, R. (1982) Effects of transportation on blood serum composition, disease incidence and production traits in young calves. Influence of the journey duration. *Annls Rech. vét.* **13**: 369-384.

Murata, H. (1989) Suppression of lymphocyte blastogenesis by sera from calves transported by road.*Br.Vet.J.* **145**: 257-262.

Nicholson, R.I., McGlone, J.J. & Norman, R.L. (1993) Quantification of stress in sows: comparison of individual housing versus social penning.*J.Anim.Sci* **71**(suppl.1): 112 (Abstr.).

Nimmo, R.D. (1980) Effect of varying levels of dietary calcium and phosphorus fed to gilts during growth, gestation and subsequent lactation. *Ph.D.Thesis*, Univ.of Nebraska, Lincoln.

Ödberg, F.(1978) Abnormal behaviours: (stereotypies). In: *Proc.1st World Cong.Ethol. Appl.Zootech.* Madrid, Industrias Graficas España. 475-480.

Parrott, R.F. & Misson, B.H. (1989) Changes in pig salivary cortisol in response to transport stimulation, food and water deprivation and mixing. *Br.vet.J.* **145**: 501-505.

Parrott, R.F., Misson, B.H. & Baldwin, B.A. (1989) Salivary cortisol in pigs following adrenocorticotrophic hormone stimulation: comparison with plasma levels. *Br.vet.J.* **145**: 362-366.

Pedersen, C.A., Ascher, J.A., Monroe, Y.L. & Prange, A.J. (1982) Oxytocin induces maternal behaviour in virgin female rats.*Science* **216**:648

Pedersen, P.E. & Blass, E.M.(1982) Prenatal and postnatal determinants of the first suckling episode in albino rats. *Dev . Psychobiol.* **15**: 349-355.

Peng, X., Lang, C.M., Drozdowicz, C.K. & Ohlsson-Wilhelm, B.K. (1989) Effect of cage population density on plasma corticosterone and peripheral lymphocyte populations of laboratory mice. *Lab. Anim.* **23**: 302-306.

Perrin, W.R. & Bowland, J.P. (1977) Effects of enforced exercise on the incidence of leg weakness in growing boars. *Can.J.Anim.Sci.* **57**: 245-251.

Petchey, A.M. (1993) The preferences of farrowing sows for different features of pen design. In *Livestock Environment IV*. 447-451. Proc. Am. Soc. Agric. Eng. St. Joseph, Michigan.

Petherick, J.C. (1983) A biological basis for the design of space in livestock housing. In *Farm Animal Housing and Welfare*, ed. S.H.Baxter, M.R.Baxter & J.A.C.MacCormack. *Curr.Top.vet.Med.Anim.Sci.* **24**: 103-120. The Hague, Martinus Nijhoff.

Petersen, H.V., Vestergaard, K. & Jensen, P. (1989) Integration of piglets into social groups of free-ranging domestic pigs. *Appl. Anim. Behav. Sci.* **23**: 223-236.

Pettigrew, J.E. & Tokach, M.D. (1991) Nutrition and female reproduction. *Pig News & Info.* **12**: 559-562.

Pettigrew, J.E. & Tokach, M.D. (1993) Metabolic influences on sow reproduction. *Pig News & Info.* **14:** 69N-72N.

Phillips, P.A. & Fraser, D.(1993) Development in farrowing housing for sows and litters. *Pig News & Info.* **14**: 51N-55N.

Phillips, P.A., Fraser, D. & Thompson, B.K. (1991) Preference by sows for a partially enclosed farrowing crate. *Appl. Anim. Behav. Sci.* **32**: 35-43.

Pierce, D.W., Friend, T.H., Lay Jr., D.C. & Bushong, D. (1993) Short-term adaptation of second parity sows to farrowing crates after gestating in crates or group pens. *J.Anim.Sci.* **71**(suppl.1): 25 (Abstr.).

Poindron, P. & Le Neindre, P. (1980) Endocrine and sensory regulation of maternal behaviour in the ewe. *Adv.Stud.Behav* **11**: 76-119.

Potter, M.J. (1987) Behaviour and heart rate in chicks. Ph.D. Thesis University of Reading.

Price, S. & Sibly, R.M.(1991) Heart-rate and behaviour in farmed red deer. (poster) at *S.V.E. 25th Int.Congress.*

Pryce, C.R, Abbott, D.H, Hodges, J.K. & Martin, R.D.(1988) Maternal behaviour is related to prepartum urinary œstradiol levels in red-bellied tamarin monkeys. *Physiol. Behav.* **44**: 717-726

van Putten, G.(1980) Objective observations on the behaviour of fattening pigs. *Anim. Regul.Stud.* **3**: 105-118.

van Putten, G. & Elshof, W.J. (1978) Observations on the effect of transport on the well-being and lean quality of slaughter pigs. *Anim. Regul. Stud.* **1**: 247-271.

Raeside, J.I. (1963) Urinary œstrogen excretion in the pig during pregnancy and parturition. *J.Reprod.Fertil.* **6**: 427-431.

Ratcliffe, H.L., Luginbuhl, H., Schnarr, W.R. & Chacko, K. (1969) Coronary arteriosclerosis in swine: evidence of a relation to behaviour. *J.Comp. Physiol. Psychol.* **68**: 385-392.

Rantzer, D.(1993) Weaning of pigs in a sow-controlled and a conventional housing system for lactating sows. *Livestock Environment IV.* Proc. ASAE meeting 1993. 468-474.

Reinhart, G.A. & Mahan, D.C. (1986) Effect of various calcium:phosphorus ratios at low and high dietary phosphorus for starter, grower and finshing swine. *J.Anim.Sci.* **63**: 457-466.

Reite, M., Harbeck, R.& Hoffman, A.(1981) Altered cellular immune response following peer separation.*Life Sci.* **29**: 1133-1136

Robertson, H.A , Dwyer, R.J. & King, G.J. (1985) Œstrogens in fetal and maternal fluids throughout pregnancy in the pig and comparisons with the ewe and cow. *J.Endocr.* **106:** 355-360.

Robertson, H.A. & King, G.J.(1979) Conjugated and unconjugated œstrogens in fetal and maternal fluids of the cow throughout pregnancy.*J.Reprod.Fertil.* **55**: 462-470.

Robertson, J.B., Laird, R., Hall, J.K.S., Forsyth, R.J., Thomson, J.M. & Walker-Love, J. (1966) A comparison of two indoor farrowing systems for sows. *Anim. Prod.* **8**: 171-178.

Rousseaux, C.G., Gill, I. & Payne-Crosten, A. (1981) Femoral fractures in pigs associated with calcium deficiency. *Austr.Vet.J.* **57**: 508-510

Rowland, L.O., Fry, J.L.,Christmas, R.B., O'Steen, A.W. & Harmes, R.H. (1972) Differences in tibia strength and bone ash amongst strains of layers.*Poult.Sci.* **51**:1612-1615.

Rudd, A.R., Mendl, M.T.,Simmins, P.H. & Broom, D.M. (1992) Behavioural consequences of allowing the farrowing and lactating sow greater freedom. *J.Anim.Sci.* **70**: 168 (Abstr.).

Rudd, A.R., Simmins, P.H., Mendl, M.T. & Malkin, S. (1993) Production comparisons between farrowing crates and community farrowing systems. *Anim. Prod.* **56**: 423 (Abstr.)

Rundgren, M., Lundström, K., Edfors-Lilja, I. & Juneja, R.K. (1990) A within-litter comparison of the three halothane genotypes 1. Piglet performance and effects of transportation and amperozide treatment at 12 weeks of age. *Livestock Prod.Sci.* **26**:137-155.

Rushen , J. (1991) Problems associated with the interpretation of physiological data in the assessment of animal welfare. *Appl.Anim.Behav.Sci.* **28**:381-386.

Rushen , J., De Passille, A-M.B. & Schouten, W.(1990) Stereotypic behaviour endogenous opiods and post - feeding hypoalgesia in pigs. *Physiol.Behav.* **48**: 91-96.

Sainsbury, D.(1980) *Poultry Health and Management.* Granada, London.

Sato, Y. & Hasegawa, S. (1993) Kinetic analysis on standing and lying behaviours of cattle. *Livestock Environment IV.* ASAE proceedings 330-338

Schmid, H. (1993) A practicable, behaviour specific housing system for farrowing and lactating sows. In *Livestock Environment IV.* 33-39. Proc. Am. Soc. Agric. Eng. St. Joseph, Michigan.

Schmidt, M. (1982) Abnormal oral behaviour in pigs. *Disturbed Behaviour in Farm Animals*, ed.W.Bessei, *Hohenheimer Arbeiten*, **121**: 115-132. Stuttgart: Eugen Ulmer.

Schneidermann, N. (1983) Behaviour, autonomic function and animal models of cardiovascular pathology. In *Biobehavioural Bases of Coronary Heart Diseases*, eds. T.M.Dembrowski, T.H.Schmidt & G.Blumchen. 304-364. Karger, Basel.

Schouten, W.G.P., Rushen, J. and De Passillé, A-M.B. (1991) Stereotypic behaviour and heart rate in pigs. *Physiol.& Behav.* **50**, 617-624.

Schouten, W.G.P. & Wiepkema, P.R.(1991) coping styles in tethered sows. (poster) *S.V.E. 25th International Congress.*

Seabrook, M.F.(1984) The psychological interaction between the stockman and his animals and its influence on performance of pigs and dairy cows. *Vet.Rec.* **115**: 84-87.

Siegal, H.I. & Rosenblatt, J.S.(1975) Œstrogen-induced maternal behaviour in the hysterectomised/ ovariectomised virgin rat. *Physiol. Behav.* **14**: 465-471.

Simonsen, H.B. (1993) PST treatment and leg disorders in growing swine: a welfare hazard? *Livestock Prod.Sci.* **36**: 67-70.

Sinclair, A., Edwards, S.A., Cruickshank, A. & English, P.R. (1993) behaviour and performance of lactating sows and piglets housed individually or in a multisuckling system. *Anim.Prod.* **56**: 476 (Abstr.).

Smidt, D. ed. (1983) Indicators relevant to farm animal welfare. *Curr.Top.vet. Med Anim. Sci.* **23** Martinus Nijhoff, The Hague.

Smith, A.T. (1987) Current pig production systems. In *Pig Housing and the Environment*, eds. A.T.Smith & T.L.Lawrence, BSAP Occasional Publication, BSAP, Edinburgh **11**: 1-8.

Smith, J.J. & Kampine, J.P. (1980) *Circulatory Physiology*. London. Williams & Wilkins.

Smith, W.J. & Robertson, A.M. (1971) Observations on injuries to sows confined in part slatted stalls. *Vet.Rec.* **89**: 531-533.

Sokal, R.R. & Rohlf, F.J. (1981) *Biometry*. W.H.Freeman, San Francisco.

Sommer, B.(1979) Zuchtsauen in Kastenstand - und in Gruppenhaltung - Rauschverhalten, Gerburten, Fruchbarkeit und Schaden am Bewegungsapparat. Inaugural dissertation, Ludwig-Maximilians Universität, München, 1-203.

Sommer, B., Sambraus, H.H., Osterkorn, K. & Krausslich, H.(1982) Heat behaviour, birth reproduction performance and reasons for losses of sows in cage and group housing. *Zuchtungskunde*, **54**: 138-154.

Soussignan, R. & Koch, P.(1985) Rhythmical stereotypies (leg-swinging) associated with reductions in heart rate in normal school children. *Biol.Psychol.* **21**: 161.

Spicer, E.M., Driesen, S.J., Fahy, V.A., Horton, B.J., Sims, L.D., Jones, R.T., Cutler, R.S. & Prime,R.W.(1986) Causes of preweaning mortality on a large intensive piggery. *Aust.Vet.J.* **63**: 71-75.

Sprecher, D.J., Leman, A.D. & Carlisle, S. (1975) Effects of parasympathomimetics on porcine stillbirth. *Am.J.Vet.Res.* **36**: 1331-1333.

Stephens, D.B.(1971) Piglet survival: A review of some physiological considerations. *Vet.Ann.* **12**: 64-73.

Stephens, D.B. & Toner, J.N. (1975) Husbandry influences on some physiological parameters of emotional responses in calves. *Appl.Anim.Ethol.* **1**: 233-243.

Steplewski, Z, Goldman, P.R.& Vogel, W.H.(1987) Effect of housing stress on the formation and development of tumours in rats.*Cancer Lett.* **34**: 257-261.

Steplewski, Z. & Vogel, W.H.(1986) Total leucocytes, T-cell subpopulation and NKC activity in rats exposed to restraint stress. *Life Sci.* **38**: 2419-2427.

Stolba, A.(1982) A family system of pig housing. *Proc. Symp.Alternatives to Intensive Husbandry Systems.* UFAW:Potters Bar.

Svendsen, J. & Bengtsson, A.C.(1982) Perinatal mortality in pigs: herd investigations of pigs with splayleg. Proc. 7th Int.Pig Vet.Soc.Cong. Mexico City, p164.

Svendsen, J. & Olsson, A.C.(1991) The effect of different housing systems on sow health. *Proc. 42nd Ann.Meet.* EAAP,Berlin.

Swarbrick, O. (1986) The welfare during transport of broilers, old hens and replacement pullets. In: The Welfare of Animals in Transit. BVA AWF London. 82-97.

Sybesma, W., Westerink, N.G., Cortiaesen, G.P. & van Logestijn, J.G.(1978) *Kongressdokumentation I.* **24** : 1-7. Europäischer Fleischforscherkongress. Kulmbach.

Syme, L.A. & Elphick, G.R.(1982) Heart-rate and the behaviour of sheep in yards. *Appl.Anim.Ethol.* **9**: 31-36.

Terlouw, E.M.C., Lawrence, A.B. & Illius, A.W. (1991) Influences of feeding level and physical restriction on development of stereotypies in sows. *Anim.Behav.* **42**: 981-991.

Terlouw, E.M.C. & Lawrence, A.B.(1993) Long-term effects of food allowance and housing on development of stereotypies in pigs. *Appl.Anim.Behav.Sci.* **38**: 103-126.

Thornton, K. (1990) from *Outdoor Pig Production* : Farming Press,Ipswich.

Tillon, J.P. & Madec, F. (1984) Diseases affecting confined sows. Data from epidemiological observations. *Ann.Rech.vét.* **15:** 195-199.

Tokuriki, M. (1973a) Electromyographic and joint-mechanical studies in quadrupedal locomotion. I. Walk. Jap.J.vet.Sci. 35: 433-446.

Tokuriki, M. (1973b) Electromyographic and joint-mechanical studies in quadrupedal locomotion. II. Trot. Jap.J.vet.Sci. 35: 525-533.

Tokuriki, M. (1974) Electromyographic and joint-mechanical studies in quadrupedal locomotion. III. Gallop. Jap.J.vet.Sci. 36: 121-132.

Vallenga, L., van Veen, H.M. & Hoogebrugge, A. (1983) Mortality, morbidity and external injuries in piglets housed in different housing systems. I. Farrowing house. *Vet.Quart.* **3**: 101-106.

Varley, M.A.(1981) The time of weaning and its effects on reproductive function. In: *Control of Pig Reproduction.* (Eds; D.J.A.Cole & G.R.Foxcroft) London, UK, Butterworth's, 459-478.

Vermeer, H.M., Hoofs, A.I.J. & Plagge, J.G. (1993) Piglet mortality reduction by farrowing pen design. *Livestock & Environment IV*, 820-827. Proc. Am. Soc. Agric. Eng. St. Joseph, Michigan, 1993.

Vestergaard, K. & Hansen, L.L. (1984) Tethered v. loose sows. Ethological observations and measures of productivity. I. Ethological observations during pregnancy and farrowing. *Ann.Rech.Vet.* **15**: 245-256.

Weber, R., Friedli, K., Troxler, J. & Winterling, C. (1993) The influence of computerised individual feeding system on the behaviour of sows. In *Livestock Environment IV*, 495-502 Proc. Am. Soc. Agric. Eng. St Joseph, Michigan, 1993.

Webster, A.J.F. (1967) Continuous measurement of heart - rate as an indicator of the energy expentiture of sheep.*Br.J.Nutr.* **21**:769-785

Wennrich, G. (1975) Untersuchungen über die Bewegungsaktivität von Haushennen. *Arch Geflügelkd.* **39**: 113-121.

Whatson, T.S. & Bertram, J.M. (1983) Some observations on mother-infant interactions in the pig (sus scrofa). *Appl. Anim. Ethol.* **9**: 253-261.

Whittemore, C.T. (1993) *The Science and Practice of Pig Production.* Longman Scientific & Technical, Harlow, UK.

Whittemore, C.T. & Fraser, D. (1974) The nursing and suckling behaviour of pigs. II. Vocalisations of the sow in relation to suckling behaviour and milk ejection. *Br.vet.J.* **130**: 346-356.

Widowski, T.M. & Curtis, S.E. (1990) The influence of straw, cloth tassel, or both on the prepartum behaviour of sows. *Appl. Anim. Behav. Sci.* **27**: 53-71.

Wiepkema, P.R (1987) Behavioural aspects of stress. In *Biology of Stress in Farm Animals: an Integrative Approach.* ed. P.R.Wiepkema & P.W.M.van Adrichem. *Curr. Top. vet. Med. Anim. Sci.* **42**: 113-183. Dordrecht: Martinus Nijhoff.

Wiepkema, P.R , Broom, D.M , Duncan, I.J.H. & van Putten, G.(1983) Abnormal behaviours in farm animals. *Report of the C.E.C.* Brussels.

de Wilt, J.G. (1984) The lying behaviour of veal calves in different housing systems. The Proceedings of the International Congress on Applied Ethology of Farm Animals, Kiel

Wood-Gush, D.G.M (1988) The relevance of the knowledge of free-ranging domesticated animals for animal husbandry. *Proc.Int.Cong.Appl.Ethol Farm Animals*, Skara, eds. G.van Putten, J.Unselm & K.Zeeb. Darmstadt: K.T.B.L.

Wright, T.M. & Hayes, W.C. (1976) Tensile testing of bone over a wide range of strain rates: Effects of strain rate, microstructure and density. *Medical and Biological Engineering* **14**: 671-679.

Wutzen, J., Lewicki, Z., Rozycka, Z., Ceremuzynski, L. & Barcikowski, R. (1987) Effects of immobilization stress on histological, histochemical and electron-microscopic changes in porcine myocardium. *Mat.Med.Pol.* **19**: 78-84.

Yamamoto, S. (1986) The relationship between heart-rate and heat production of laying hens using fast response calorimetry.*Jap.J.Zootech.Sci.* **56**: 947-953.

Zarrow, M.X , Gandelman, R. & Denenberg, V.H. (1971) Prolactin; is it an essential hormone for maternal behaviour in the mammal? *Horm.Behav.* **2**: 343-350.

Zanella, A.J. & Zanella, E.L. (1993) Nesting material used by free-range sows, in Brazil. In *Proc. of the Int.Cong. on Appl. Ethol.* p411-413, ed. M.Nichelmann, H.K.Wierenga & S.Braun. Humboldt University, Berlin.